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INDUCTION OF ELECTRIC CURRENTS AND INDUCTION COILS.

BY PROF. ELIHU THOMSON.

[*A lecture delivered before the Franklin Institute, January 26, 1891.*]

The lecturer was introduced by Prof. Edwin J. Houston, and spoke as follows:

MEMBERS OF THE INSTITUTE, LADIES AND GENTLEMEN:

Since the memorable experiment of Faraday, about fifty years ago, by which he demonstrated that an electric current could produce another current by action called induction through the intervening space between the two conductors, an increasing interest has been attached to the phenomenon itself by the varied forms under which it occurs, the accompanying actions displayed and the utility of the apparatus.

One form of Faraday's experimental apparatus deserves particular notice, inasmuch as it contained the essentials of the much more modern apparatus of like character. It consisted of a ring of iron which had two coils wound on it, as seen in *Fig. 1*. He found that on passing a current through one coil there could be obtained a second or secondary current in the other at the moments of making and breaking the circuit of the first coil. These effects are now so well known that it is not necessary to dwell on them. They are examples of the phenomena of electro-magnetic induction, which Faraday investigated so ably and so thoroughly that he virtually laid the foundation for

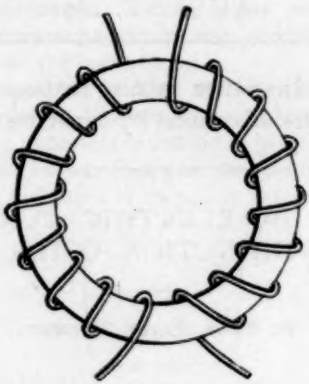

FIG. 1.

the dynamo machine, the electric motor of the present types, and the induction coil or transformer. Faraday's ring, with its two windings, is found, modified only to a slight extent, in the induction coils at present so extensively used in distribution of currents for lighting.

Long prior to these experiments of Faraday it had been known that an electrified or charged body brought near another body of conducting character, such as a metal ball on an insulating stand, would, under the inductive action of the charged body, become itself electrified, but in a special way, the nearest portion being electrified oppositely in kind of charge to the charge of the inducing body, a charge of like kind being repelled, as it were, to the more

distant portions of the insulated conductor. Without going into any consideration of these facts it will be sufficient to simply state that the principles of static induction enter into the construction of many of the most useful devices and apparatus of the electrician, chiefly in condensers.

In like manner it had long been known before Faraday's experiment that a magnet would produce other magnets inductively and give rise to changes of magnetism in other pieces of iron or steel merely by its presence near them. The experiments of Faraday showed the actions of electric currents to be similar, in that under certain conditions a current of electricity could develop a current in an adjoining conductor, or if such a conductor were not a complete circuit that it could develop charges of opposite name on

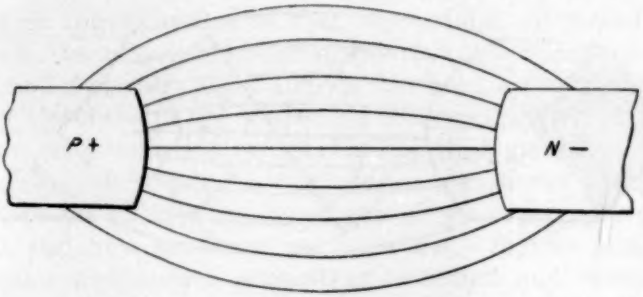

FIG. 2.

two parts of the conductor. Moreover, he showed that these effects were due not to any direct action of the current working at a distance, but in fact to the production of magnetism in the medium surrounding the conductor.

In *Fig. 2*, let *P* represent a charged conductor, and *N* another conductor connected to earth brought near to it or within a certain distance. There will at once arise a static inductional effect, whereby if *P* is + or positive, the body *N* becomes — or negative, and lines of inductional stress or electrostatic stress may be conceived as joining the two bodies as shown.

This figure will equally represent the effect of bringing an iron body *N* near to a magnetic pole *P*, in which case the lines would represent the lines of force or magnetic

lines joining the two. But suppose that the bodies *P* and *N*, when in the condition as first stated, that is, with an electrostatic stress existing between them, and, therefore, possessed of opposite electrical charges, be joined by a wire, as in *Fig. 3*.

Now, it will be found that a current will flow in the wire as assumed from *P* to *N* though the direction is a convention at present. An action in the wire occurs which we call the flow of the current and this flow continues so long as there exists any stress as represented by the lines joining *P* and *N*. But the moment of the beginning of current flow is attended by the evolution or formation of a system of forces or actions called magnetic actions and they are represented by closed bands surrounding the wire convey-

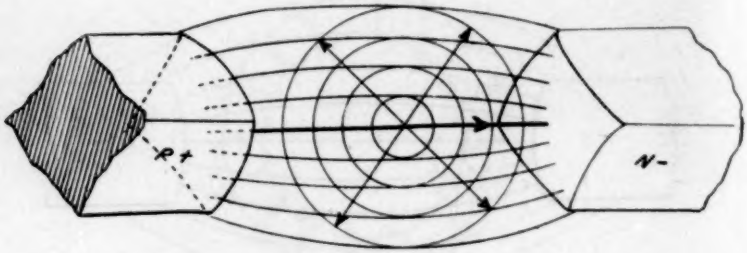

FIG. 3.

ing the current. They are at right angles at any point to the lines of electrostatic stress, and the influence which they represent proceeds outwardly from the conducting wire in a direction at right angles to both the magnetic bands or lines and to the lines of electrostatic stress and with a velocity equal to that of light, if the influence is unretarded.

The magnetic bands or whirls are the lines of magnetic force of Faraday. We then have three things at right angles, just as in space we have length, breadth and thickness, or distance. Can it be possible that in these conditions of electrostatic stress, magnetic lines, and propagation with the velocity of light, we have an exemplification of the properties of space of three dimensions, such that if we fully understood the one we would understand the

other? This is a view which is not improbable, seeing that the ether, or universal space-filling medium (or space maker perhaps), is known now to be the electrical medium.

Here then we have a harmony of effects pointing clearly to a common cause for all these actions of static induction, magnetic induction and current induction. Indeed, to-day we have learned to regard an electric current in a wire or conductor as simply a part of the thing occurring, the core, as it were, of a disturbance not limited to the wire itself, but extending outwardly therefrom in weakening force to limitless distances, and that the energy transferred by a current in a wire is conveyed, to use a sort of contradictory statement, by the medium outside the wire.

In short, we have come to believe more fully than ever before in the existence of that mysterious, all-pervading medium, the ether, and that magnetism, electricity—both static and dynamic—light and radiant heat, are things connected closely with the properties of the ether, which as a medium may be called broadly an electrical medium. We are accustomed to look to this medium also as the cause of gravitational effects, but by virtue of what property produced, and how produced, we know not. In like manner molecular and atomic attractions, cohesion and chemical affinities must be dependent on the properties of the ether, and cohesion may probably be gravitational force intensified by proximity in obedience to some unknown law. These considerations are, however, not explanations of these obscure yet most familiar phenomena.

It is not our purpose, in the present lecture, to do more than point out some of the more important effects produced by electric currents acting inductively, aside from other forms of induction, and to point out the great importance which these effects and the apparatus which yield such effects have come to occupy in the study and practice of the electrical arts.

In particular, we desire to deal with the inductive actions of those currents, the direction of which is constantly changing and at varying rates of change. Such currents are called alternating currents, the number of times per second

that the reversal takes place being called the rate of alternation, and half that number being known as the periodicity or frequency.

While the consideration of the actions occurring in magneto- and dynamo-electric machines would not be excluded by the title of the present lecture, since in such apparatus we have a case of electric current induction, yet it is thought best to confine ourselves to the consideration of the special instances in which one electric current sets up other currents or acts inductively.

Let us take first the case of a simple long wire or portion of an electric circuit through which a battery current may be sent by closing a contact or key. Close observation would show that such current did not rise at once or immediately to its full value but was very slightly delayed unless the wire were very long, in which case the delay would be quite considerable. It will have suffered an impeding action or "impedance," as it is now termed. This was Faraday's "extra current on making," in opposite direction to the current itself. Winding the long wire into a coil was found to increase this impedance and putting an iron core into the coil still further increased it. While in small coils or short conductors the action is of very slight duration, ending in a small fraction of a second after closing the circuit, yet in large coils with massive iron cores the impeding action may last a few seconds. In these cases it is said that the current develops a counter pressure to its own flow, or a counter electro-motive force.

Now let us consider the current flowing at its full value and an attempt to open the circuit or cut off the current. We have again a delaying action, a tendency of the current to force a brief continuance of its flow or to fall off gradually. This is manifested by a spark at the opening contacts which, with long and large coils, may become a flame of several inches in length. This was Faraday's "extra current on breaking"—more properly a continuance of flow resulting from a negative impedance, or addition to the pressure or electro-motive force of the current.

This effect is employed in many forms of apparatus, a

good example of which is the extra current coil or spark coil used in gas lighting by electricity. In this case a weak battery current is closed through a coil of wire wound on an iron core and the circuit carried to the gas burner, where, upon turning on the gas, the contacts at the burner are briskly separated, so as to cause an extra, current spark, which lights the gas. The battery current alone would not yield a spark of sufficient length and heating effect, and so the coil and core are introduced into the circuit. We find, in addition, that these actions are the more intensified the greater the capacity of the circuit for magnetic effects and changes. Hence, the presence of a large iron core which can gain and lose magnetism in accordance with the rise and fall of current, greatly enhances these effects, which are called oftentimes self-inductive effects, because the current itself produces them on itself. The magnetic changes, indeed, appear to be the cause of the impedance. A gain of magnetism in the surrounding medium causes a back pressure, which slows the current when put on, and a loss of magnetism causes a forward pressure or addition to the pressure of the current, which has the effect of prolonging the flow at diminishing amount and preventing absolutely sudden stoppage.

The study and knowledge of these simple facts are of the greatest importance in all departments of electrical work, from telephony to electric railways, and the property of impedance is either a bugbear or a welcome assistance in the solution of many electrical problems.

Naturally, when a current which alternates in direction many times a second is passed in a coil there is produced an impedance to the current in much more striking degree on account of the fact that such current may be considered to be a current which is started and stopped frequently, while the changes of magnetism are made much more pronounced by the reversals of the direction of current reversing the magnetic effects on which the impedance depends.

This action must not be confounded with resistance to a current, as it is altogether of different nature, for resistance has its effect whether the current change its amount or

direction or not, while impedance is present only with changing currents. The former is like a friction, the latter somewhat like inertia.

In telegraphy on very long lines with many instruments, impedance may limit the speed of transmission of signals. In telephony on long lines and with a number of coils or magnets in the circuit it softens, weakens and blurs the speech waves. Hence, in the improved telephonic instruments arrangements are made to cut out all coils unessential to speech transmission during the use of the instrument. In electric lighting with continuous currents the property under consideration, may, if not guarded against, cause damage to insulation on sudden rupture of circuits, or, on the other hand, it may be used to steady a current where such current would otherwise be subject to quick fluctuations,

Again, the property of impedance is slightly detrimental on long lines conveying alternating currents, but on the other hand it is of the greatest value in regulating and controlling the distribution of such currents, checking their flow and increasing such flow at will. Coils which may be called "reaction coils," "impedance coils," "choking coils," "kicking coils," are inserted into a circuit with alternating currents and act to cut down the current flow, not by their resistance (which is slight), but by their impedance, which may be made much or little as desired. Variable reactive coils, give a flexibility not otherwise obtainable. We must emphasize the fact that a resistance can check a current, but involves a loss of energy of the current, which energy is reduced to heat in the resistance, while a "reactive coil" can check the flow and cause loss of only a slight amount of energy in doing so. To Prof. Joseph Henry, it is believed, is due the discovery of this action of impedance in electric circuits, and a movement is on foot to call the unit measure of impedance the henry, in honor of this great electrician and scientist.

Suppose, now, that, having a coil wound upon a core, the structure is such that it gives a considerable reaction or impedance to the current. If we now wind a second coil

along-side the first and do not connect its ends to close its circuit, we shall find that the actions of the first coil are unaffected, but the moment we close the second coil there is a great change produced. Indeed, the impeding effect of the first coil is very much weakened, though it does not disappear. Here we have a case of induction of currents with another parallel circuit. We have, in fact, an induction coil, the secondary coil of which, as it is termed, is closed on itself and might be replaced by a set of rings around the first coil or a tube of copper, or the like. If we examine what occurs in the second or secondary coil, we will find that at every increase of current in the first or primary coil there is a current produced moving oppositely in the secondary, and on the cutting off of the primary there is a current in the same direction as the primary. The induction coil has long been known, and dates from Faraday's experiments, but those forms of it called Page's helix and the Ruhmkorff coils, have been used for a considerable period to obtain from a battery current sent intermittently through a primary coil of comparatively coarse wire, very high pressure discharges from the fine and long secondary wire wound parallel thereto. Such coils have also been used in medical coils in many modifications, and more recently in the transmitter boxes of telephones, to cause a low-pressure varying current to induce in the line circuit at high pressure a similar varying current representing the waves of speech.

The Ruhmkorff coil, however, in its improved and effective form, is not simply what I have described, but much more. There is a condenser of large surface attached to the primary coil on each side of the break or set of contacts which open and close the battery connection to it. The condenser, of course, is as usual simply extended surfaces of tin-foil separated by paper insulation, one surface being connected to one side of the break and the other to the other side. Its function has been described as being that of suppressing the spark, breaking the primary by taking into it the extra current or prolonged discharge which makes the spark. It not only does this, but being the

recipient of a charge in the same direction as the battery current, it discharges itself instantly thereafter and gives a reverse discharge through the primary coil. These actions are so very sudden that they amount to a very quick alternation of the primary current. Hence, the condenser is easily seen to greatly intensify the effects for which the coil is intended. It is well known that the condenser used may be made too small in surface or too large to give the maximum effects in any case.

With alternating currents passed through the primary coil the result is that we get alternating currents in the secondary coil. The applied currents are in the form of electric waves, which may be of a pitch of a few waves per second up to a large number. I have experimented with such currents up to 8,000 reversals per second, or 4,000 complete waves of current per second. In such cases the condenser is not needed, though it may under special conditions act in a measure to increase the pressure of the currents as it does in the Ruhmkorff coil. In fact, such effects have been noticed in the recent Ferranti undertaking in London, where the condenser effect of the mains for carrying the primary currents to induction coils has resulted in increasing the potential or pressure of current in London considerably above that existing at the station at Deptford, which station supplies the current. The effect, though unexpected and apparently anomalous at first, was readily seen to be due chiefly to the mains themselves acting as condensers.

Induction coils, as now used in electric lighting, are of a variety of forms and have been given a variety of names. They are sometimes called converters, or again transformers. It is a matter of taste whether one shall call them induction coils, which they are, or converters or transformers, though of the two latter names the term transformer is apparently more widely used. Such apparatus usually differs from the Ruhmkorff coil in having the secondary winding the coarser wire of the two, and, consequently, their function usually is to take a higher pressure current supplied from a station and lower it for use in working incandescent lamps on the local or secondary circuit.

The actions of transformers may be briefly described, though a book might easily be written extending into many interesting details of their structure and performance—most of which would be out of place here. The modern transformer consists of two coils and an iron core for the coils. The core may be a closed core, as when the iron of which it is made is carried over the outside and connected into a closed band or closed magnetic circuit, or it may be an open core, where the magnetism passes into the air in completing its path between ends of an iron core, which are separated some distance. These differences introduce differences of action, which will not be discussed now, as they are largely of a technical character.

Suppose, now, that such a structure has its secondary coil open or unconnected with lamps. In such case, if an alternating current be passed in the primary coil of the apparatus, it "reacts" only. It displays the action of impedance as referred to before. This, with a well-proportioned coil, limits the current which passes to a very small amount, which current, small though it be, does not even then represent a waste of current energy except in small part. If, now, a lamp be lighted by connection with the secondary coil the current required for it is induced from the primary, but this action partly takes away the impeding action, and, as a consequence, the current taken by the primary from the line is proportionally increased. This assumes the case of constant pressure of current on the mains, the condition aimed at in practice.

As lamp after lamp is added in multiple or parallel connection in the secondary circuit the primary impedance falls off, and is only restored when a corresponding increase in the primary current takes place, together with the increase of current in the secondary. This means that if one ampère of current produces ten ampères on the secondary at a pressure of one-tenth of the primary circuit pressure, each increase of an ampère in the secondary coil would cause an addition of one-tenth ampère to the current in the primary coil. Briefly, the reason for this is that since the current in the primary is subject to impedance due to magnetic

changes produced in the iron core, and the secondary current, as it increases, tends to lessen the magnetism and consequently the changes in it, the impedance to the primary current is likewise lessened and the primary current increases to an extent such as to overcome the opposition of the secondary currents and restore the varying magnetism to its original amount. In the majority of transformers, also, the current induced in the secondary is at any moment moving in the opposite direction around the core from that of the primary current waves, and so acts to oppose the effect of the primary in magnetizing the core.

It would take up too much time and carry us beyond the

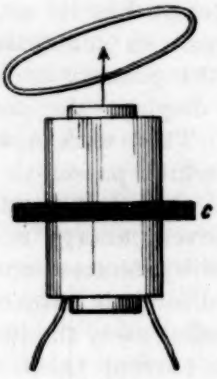

FIG. 4.

FIG. 5.

limits of the present lecture to study the effects of the lines of magnetic force in these instances. It must suffice to state that the actions of transformers are beautifully exemplified and made clear by such a study and the regulating actions just described are seen to depend on the interaction of the currents in the two circuits, occurring through the lines of magnetism or the magnetic field which they jointly set up.

In the case of a transformer put upon closed circuit, *i. e.*, with its secondary circuit or coil ends connected solidly together, the impedance or reaction in the primary almost disappears and if working as in practice, the primary and also the closed secondary circuit would receive current

in such large amount as to overheat and destroy the coils unless safety cut-off appliances were provided.

This is exemplified by an experiment easily tried. A closed ring of copper is placed over the upright coil and core *c*, *Fig. 4*, here, and alternating currents passed through the large coil which is now the primary. Currents of great vigor are set up in the closed ring and may rise to a value in heating effect such as to bring the ring up to bright redness, or even melt it. The energy is abstracted by the ring not from the air but from the ether surrounding the coil and core. If, however, the ring be free to move and not exactly over the centre of the coil and core it will be thrown

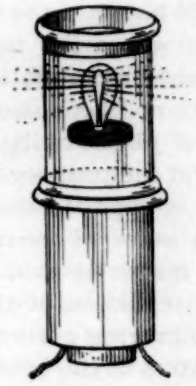

FIG. 6.

violently away or repelled and thus saved from overheating. These repulsive effects of induced currents are so striking and varied that it will be of interest to study them further.

It will be found that a copper ring or plate placed over the end of the coil, the core of which forms an alternating magnet, will even be supported for a moment in free air, or if guided laterally will remain suspended. The suspended ring will uphold one or more other rings placed near it, and will attract them into parallelism with itself, *Fig. 5*. Closed coils, pieces of metal, coins, etc., may be repelled from the field in this way.

A small incandescent lamp and coil, *Fig. 6*, suitably mounted and partly balanced in front of the pole, will be lighted and

at the same time be repelled in such way as to give a uniform brilliancy, whatever the strength of the current in the primary, or independently of variations of the same. If the lamp and coil be floated in water in a glass vessel placed over the alternating magnet pole the lamp is lighted and floated under the water by the repelling effect, and regulates its position and brilliancy as before. The magnetic waves leaving the pole, of course, penetrate the glass and water without hindrance.. Interposing a heavy plate of copper between the pole and lamp coil will cut off, or screen off the effect, for the reason that the magnetic waves are then intercepted by the heavy sheet and beaten back or reflected by it. From these experiments it will be seen that there is a strong repulsive effort exerted between the primary and secondary coils of a transformer where the two lie adjacent on the same core. The reason of the repulsion has been discussed in various publications, and been shown by me to be due to lag or displacement of phase, as it is termed. Briefly, it depends on the fact that the primary and secondary currents are for the most part in opposite directions of flow around the core during each wave of current, and each current tending to produce a magnetic field which opposes that of the other, results in repulsion of the coils or circuits in which such oppositely moving currents circulate.

Following a suggestion of the Secretary of the Institute, I have improvised an experiment which I am told is very similar in effect to a "mystery" shown in connection with a "certain motor" which has been before the Philadelphia public for the past seventeen years. I bring forward this experiment with no hope that it will revolutionize modern methods or give us power for nothing, as the certain motor, or perhaps uncertain motor, is claimed to be able to do when developed. On the table is a tall glass jar, a sort of hydrometer jar, which was found in the room adjoining this hall. It rests on a table or rather on a heavy glass plate laid on the table, as you see. In the jar is a body which has sunk to the bottom of the water which fills the jar. It is a glass bulb loaded with a few turns of bare copper wire coiled up and heavy enough with the bulb to just

sink. At my command you see the body rise briskly to the top of the water, a distance of twelve inches, and sink again at my indication that it shall so act. I have no need to sound "sympathetic" notes or "antipathetic" notes as I am informed is sometimes done in connection with the "certain motor mystery," which no one is allowed to investigate. My assistant simply closes or opens a switch which sends an alternating current into or cuts it from a concealed coil just below the table top, a coil which I found as a part of the stock of insulated wire in an electric supply shop near this hall. I have taken no especial pains with this experiment and I am informed by Dr. Wahl, your Secretary, that the effect is strikingly like the "mystery" alluded to above. There are other ways possible in which such an effect might be obtained by simple means, but their discussion would be foreign to the subject in hand.

Some time after I had discovered this repulsive action and prepared to investigate it more fully, it occurred to Mr. M. J. Wightman, an associate, and myself, to try the effect of closed circuits or bands subjected to the induction of an alternating magnet, on copper discs, bands, or pieces of iron. It was reasoned out that these would move if allowed to do so. A great variety of novel and striking experiments was the result, some of which it is my purpose to present. They admit of almost indefinite extension and amplification; and it would not be possible in the time of the lecture to do more than allude to the explanation of some of the more typical actions.

They may for the greater part be regarded as effects of movable secondary circuits of induction apparatus.

Taking our upright core and coil, and placing over a plate or ring of copper *S, Fig. 7*, so that the centre of the ring or plate does not coincide with that of the pole, we have a magnetic field resulting which possesses novel and interesting properties. I call the pole a "shaded" pole or pole of shifting magnetism. It may otherwise be described as a pole in which the shaded portion of the magnetic field is lagged at each impulse of current in the coil behind the portion unshaded or free.

Naturally, the shading of the pole may be of a simple or complex character, as desired.

Placing a pivoted disc *D*, of copper, flatwise over the shaded pole so that its axis is to one side of the pole and approximately in line with the division between shaded and unshaded portions results in rapid rotation of the disc towards the shaded portion, *Fig. 7*. The direction of revolution of the disc may therefore be governed by shading the pole to the right or left of the axis of the disc. An iron disc *I*, *Fig. 8*, is revolved if held vertically over the region of the pole shaded by the closed ring or plate, or over any part of the pole near the junction of shaded and unshaded portions.

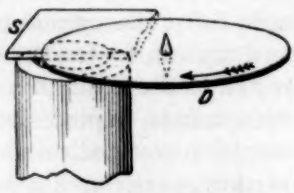

FIG. 7.

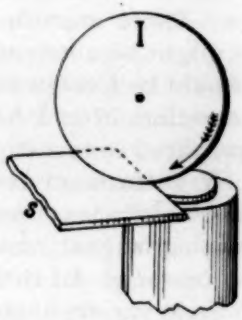

FIG. 8.

Two copper discs, laid one overlapping the other and free to turn, *Fig. 9*, and directly over the pole (in this case unshaded), are both set into rapid revolutions in directions depending on their positions over the pole.

These experiments with one or more discs and with shaded and unshaded poles may be greatly extended and a great variety of effects of rotation produced. Copper and iron discs may be used together and caused to rotate by their mutual influence on each other in the field. In this case the discs are generally placed in planes at right angles, the plane of the copper being transverse to the magnetic lines leaving the pole, and the planes of the iron disc being in line or coincident with their direction.

The copper discs may be replaced by hollow balls, *Fig. 10*, which rotate in a variety of ways. Thus, by shading the pole

and placing a copper ball over the shading plate, the ball is vigorously rotated on an axis depending on its relative place over the pole and shading plate. A certain thickness of shading plate gives the best results. The ball may revolve on a horizontal axis or with its axis either inclined or vertical. When turning with its axis horizontal it rubs its equatorial portion at great speeds over the shading plate.

A modification of this experiment is made by placing the ball in a vase of water supported over the pole shaded as before. In this case the ball rotates vigorously in the water. If a copper dish be added, and a second ball, all

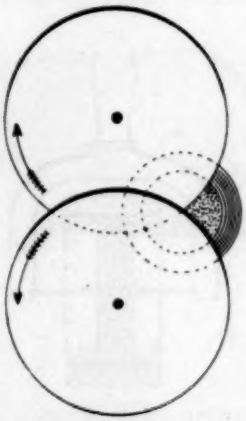

FIG. 9.

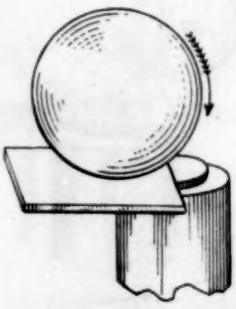

FIG. 10.

three may be maintained in a vigorous and confused activity by the shaded pole. The actions in the disc and balls are the direct consequence of the shifting magnetism of the pole, whereby as it were the lines of force act as veritable magnetic brushes to brush the discs, balls, etc., around. The hold which the lines get in the copper in causing its rotation is, of course, due to the production of induced currents in it by the moving lines of magnetism or developing field. The effect on the iron discs is due to magnetism rather than to current, the iron discs resisting slightly a change of direction of magnetization in them, which results in the shifting lines dragging the discs

around in the direction of shift or towards the delayed or shaded portion of the pole.

Some of the most curious effects are obtained by placing various shapes of iron or steel pieces over the pole and then testing them with the approximated copper or iron discs, *Fig. 11.* Few dispositions will fail to cause rotation of the discs. A more sensitive rotator, however, is a shaft mounted on delicate pivots and carrying a wheel composed of a few small discs of sheet-iron with an attached heavy copper rim overhanging the iron discs, and shown in section, *Fig. 12.*

If this device or if copper or iron discs alone be applied in the proper way in the neighborhood of pieces of iron, copper, or even brass laid on the pole, rotative effects are

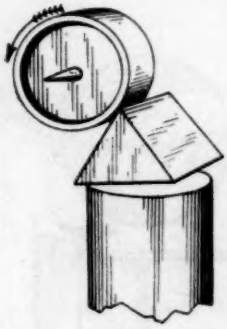

FIG. 11.

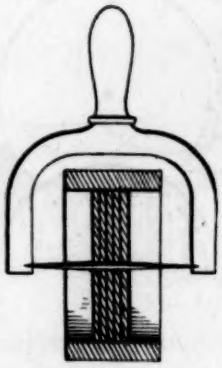

FIG. 12.

readily obtained. Thus, a steel file laid over the pole, as in *Fig. 13*, will rotate the iron discs in the direction of the arrows when they are mounted as shown, and copper discs are rotated likewise when placed near and flatwise to the file.

In this case the hardness of the steel of the file compels the magnetic change of polarity, originating at the pole, to spread laterally in a retarded manner similar in effect to the shading spoken of, but differing in cause. The shading plate of copper acts by the currents developed in it; the steel mainly by its hysteresis or resistance to changes of magnetic state, an inherent property of hardened steel.

Bent pieces of steel laid over the pole vary the actions in many ways that are quite interesting.

As a curious example of a combination of electric and mechanical actions in one device, we have an electric gyroscope constructed of a copper-rimmed rotator with iron plates or discs mounted on a shaft, a closed circuit frame of copper surrounding the same and an arm with jewel cup and counterbalance weight. This is mounted, as shown, over the alternating pole on a steel pivot set therein. Very soon the wheel of the gyroscope is set into rapid rotation and then the apparatus exhibits all the characteristic movements of the gyroscope, independently of the electric actions.

The fact that in the actions described above we obtain motion of rotation or translation is sufficient to indicate

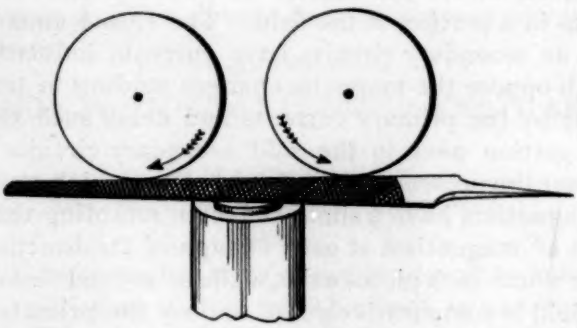

FIG. 13.

that electric motors operating by alternating currents may be constructed in accordance with the same principles. Alternating current meters have also been made in which the rotary actions have been employed to move a register at a rate depending on the current flow or consumption.

I have here one example of a small motor in which the moving part is a heavy copper disc entering the slot in a ring core upon which is wound a coil traversed by the alternating currents. The magnetic poles on each side of the slot are shaded progressively from the under side up by enclosure in copper bands let into the face of the poles. A considerable rotative force is thus obtained. Removing the disc armature of this motor and placing a silver coin at the lower edge of the slot results in the coin being lifted up and

projected from the slot above. A disc of base metal, such as lead, is not so projected while a copper disc behaves like the silver. The instrument might be arranged to quickly sort genuine silver coins from base coins, though a silver-plated copper coin would be affected about in the same manner as the alloyed silver, but pure copper would be lifted somewhat farther for the same weight and diameter of disc.

These experiments are primarly based upon the alternating magnetic field set up by an alternating primary current in a coil, and which field is modified by closed secondary coils or circuits, or by the presence of steel pieces in the field in such a manner that a portion of the field develops its effects before the other. To put it differently, a lag is set up in a portion of the field. The closed coils or plates used as secondary circuits have currents induced in them which oppose the magnetic changes tending to be brought about by the primary currents and delay such changes in that portion next to the said secondary circuits. In like manner the presence of hard steel pieces which resist change of magnetism have a similar effect in retarding the development of magnetism at each change of its direction, at the place where such pieces exist, while all around them in the air the field is comparatively free to obey the primary impulse. There results from these conditions a propagation, so to speak, of magnetism or magnetic polarity which may act on other closed circuits, or on other pieces of iron or steel to set them in motion. The movement so obtained is brought about by the continual readjustments of the moving secondary or iron piece to the shifting or propagating magnetism.

The copper rimmed iron wheel, *Fig. 12*, is so delicate a detector of shifting magnetism, that it responds to the effects of any feeble shifting which may occur in the iron core around which the primary current passes. In fact, different forms of core, whether of iron wire bundles, or of laminated structure, as bundled sheet iron, each give their own peculiar effects of shifting magnetism in accordance with the form, material and relation of the parts, and their

liability to eddy or foucalt currents or hysteresis in various positions or directions. Few cores indeed fail to show decided effects of shifting lines of magnetism at some portion of their surface, and a laminated core may be readily distinguished from a wire core by this little wheel, delicately mounted. In fact, it may be regarded as an alternating field explorer, and its indications may be of considerable value in locating sources or conditions of loss by foucalt or eddy currents, or by hysteresis.

It has been necessary to be brief in the descriptions given in this lecture, as the time has been too limited to do more than furnish food for study to those who are sufficiently interested in this important subject of current induction, in which so many developments have taken place in the recent past. The future has, of course, very much more in store.

THE RANGE OF TIDE IN RIVERS AND ESTUARIES.

BY E. A. GIESELER.
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When tidal rivers or estuaries are improved by means of works of restriction, it frequently happens, in consequence of such improvement, that the volume of discharge is diminished, not only on account of the superficial area of the river having been decreased, but also on account of a diminution of the range of tide, caused by the greater resistance, which the restricted bed offers to the passage of the tidal wave.

In the river proper, the evil consequences arising from this loss of volume are, generally, more than counterbalanced by the beneficial effects of restriction; but in the entrance the decrease of discharge frequently has undesirable consequences. Here, restriction may be difficult or entirely impracticable, and if so, then the possibility of maintaining the channel over the outer bar diminishes in the same ratio in which the volume discharged over it is diminished.

Hence, it may be said that in many cases the improvement of the river proper and the maintenance of the entrance are in a measure antagonistic to each other. The employment of the means best adapted to achieve the former is apt to be followed by consequences detrimental to the latter. A similar relation exists between the improvement of the entrance by restriction and the maintenance of the channel in the river above, and it is an important part of the task of the engineer to find, in each case, the best possible way of reconciling with each other, these conflicting interests.

One of the first questions then presenting itself in connection with the improvement of tidal rivers and their entrances, is whether or not the proposed works of restriction are apt to exercise an unfavorable influence on the tidal range of the river. While experience and good judgment will, *generally*, enable the engineer to make a sound forecast in this respect, it cannot be said that this can always be done with that certainty which the importance of the subject seems to demand. It is evident that there would be no difficulty about any such forecast, if the conditions governing tidal phenomena in rivers and the influence exercised by each of them were known. In the following, an attempt has been made to solve this question.

A tidal wave entering a river or an estuary will have its range diminished in moving upward, until it is either gradually obliterated or its further progress arrested by an impassable barrier.

This general course of events is, however, subject to modifications in each individual case, so that probably there do not exist two rivers, the tidal phenomena of which are precisely the same. In some cases, the range of tide decreases rapidly; in others, gradually. Again, it often remains unchanged for a long distance, and sometimes it even increases before the final deterioration begins.

The estuaries of the Hudson and of the Delaware, for instance, are entered at Sandy Hook and between the Capes, respectively, by tidal waves of about the same range. In the former, there is a *decrease* in range of about one-third

during the first forty miles of its upward course, while in the latter, there is within twenty miles of its mouth an *increase* in range of about the same amount.

The inference that such and similar differences are caused by the individual features of the river-beds in which the tidal waves move appears justified; and it further appears probable that, generally speaking, the most important influence is exercised by the relation between the capacity of the river-bed and the amount of service it is called upon to perform. The capacity of the river-bed is represented at each point by the cross-sectional area of the river, and the amount of service it is called upon to perform, by the superficial area of the tidal basin above. The quotient of these two may then be supposed to be a measure of the possibilities of the tidal range above, up to a point where the slope of the river bottom becomes so steep that it exercises a perceptible influence on the further progress of the tidal wave. In a general way, this line of argument is sustained by the fact that, where an increase of range takes place, we find comparatively great cross-sectional areas and small extent of tidal basin above, while, *vice versa*, where a very marked decrease of range takes place, we find comparatively small cross-sectional areas and great extent of tidal basin above. The Raritan River in New Jersey is a fair example of the former case, while the St. John's River in Florida is a striking illustration of the latter.

In order to develop, on the basis outlined above, a mathematical expression for the conditions of the river bed required for a propagation of the tidal wave with undiminished range, a comparison was made between the following rivers, for each of which more or less detailed data were available:

(1) Hudson.
(2) Delaware.
(3) Elbe.
(4) Clyde.
(5) Raritan.
(6) Savannah.
(7) Weser.
(8) Seine.
(9) Nansemond.
(10) James.
(11) St. John's.

The high-water cross-sectional area of each river was determined at as many points as the available data would allow, and for each such point the superficial area of the tidal basin above was computed; the former was then divided by the latter, and to avoid cumbrous decimal fractions, the quotient was multiplied by 1,000,000. Now, other things being equal, the same quotient must correspond to a greater loss of range in the case of a higher range than in the case of a lower range. In order to make possible a comparison between different rivers with different tidal ranges, the figures thus obtained were, therefore, reduced to a common basis by dividing each of them by the tidal range pertaining to it.

We designate, as follows:

A, High-water cross-sectional area in square feet at any point.

R, Mean tidal range in feet at the same point.

S, Superficial area of tidal basin above such point expressed in millions of square feet.

We then have for *C*, the above described coëfficient, at such a place—

$$C = \frac{A}{R\,S} \qquad (1)$$

Coëfficients found according to this expression were obtained for as many points as possible, and means of them were taken for those stretches of river on which the rate of decrease or increase of range remained the same. From the results thus obtained, which are rendered in the appended tables, it appears that, generally speaking, to the greater coëfficient there pertains the greater tendency towards constancy or even increase of tidal range, with this qualification; that the coëfficient remaining the same, the approach to constancy or to increase of range will be the closer the greater the cross-sectional area.

A striking verification of this is found in the case of the Savannah River. Besides the mean ranges at the various places, there were available 345 rises and falls observed simultaneously at Fort Pulaski and at Fort Oglethorpe,

They were grouped according to their height, and the following means obtained from them:

Number of Observations.	Average of Observed Rises and Falls at.		*Increase or Decrease of Range per 10 Miles and per Foot of Range.*
	Pulaski.	*Oglethorpe.*	
28	4·66	4·81	+ 0.046
36	5·50	5·47	0
49	6·02	5·91	— 0·027
60	6·51	6·31	— 0·050
64	7·01	6·70	— 0·067
62	7·71	7·16	— 0·109
46	8·89	7·94	— 0·166

It is seen from this table that for the smallest range, for which C of course is greatest, there is an actual gain of range, from the lower to the upper point of observation. Next comes a slightly greater range and, consequently, a smaller C, for which there is practically no change between the two points of observation; and, after that, the loss in tidal range uniformly increases with increasing range and decreasing C.

In order to define clearly the influence exercised by the coëfficient and by the cross-sectional area on the tidal range, the results rendered on the appended tables were platted on the accompanying diagram, the coëfficients C being the ordinates, and the corresponding cross-sectional areas in square feet A being the abscissas. Wherever an unchanged tidal range pertains to these two, the point determined by them has been marked on the diagram by two concentric circles, and, wherever a decrease or an increase of range pertains to them, the point determined by them has been marked by a single circle. It will be seen that the various points of no change of range are so located that an equilateral hyperbola introduced on the diagram corresponds with them sufficiently well to warrant the conclusion that it represents approximately the curve of no change of tidal range. This conclusion is further sustained by the fact that the points of decrease and the points of increase are located as they should be, the former outside and the latter inside of the hyperbola.

The axis of ordinates (the coëfficients) and a line paral-

lel to the axis of abscissas (the cross-sectional areas) are the asymptotes of this hyperbola, and it now remains to deduce its equation from the general equation of an equilateral hyperbola, referred to its asymptotes, which is

$$xy = \frac{m^2}{2}$$

in which m is the half axis of the hyperbola. In the diagram, this has been made equal to fifteen units of the y scale, and we therefore have

$$xy = 112{\cdot}5 \text{ or } y = \frac{112{\cdot}5}{x}$$

This would render y in its own scale, if x were expressed in the same; and, in order to do this, we have to consider the relation between both scales, which is—

Length of one y unit = length of 5,000 x units.

Introducing this into our equation, we obtain

$$y = \frac{112{\cdot}5}{\frac{1}{5000}x} = \frac{562{,}500}{x}$$

Now the asymptotic x axis is distant from the zero line of the y scale twenty-three units of the latter. We, therefore, have

$$\text{Coëfficient} = C = y + 23.$$

Substituting this above and remembering that x and A are identical, we now find

$$C = \frac{562{,}500}{A} + 23$$

This, in connection, with equation (1) renders

$$\frac{A}{R\,S} = \frac{562{,}500}{A} + 23 \qquad (2)$$

or

$$A^2 - A\,S\,R\,23 = S\,R\,562{,}500$$

Solving for A, we obtain

$$A = S\,R\,11{\cdot}5 + \sqrt{S\,R\,562{,}500 + S^2\,R^2\,132{\cdot}25}$$

or, in a more convenient form

$$A = S R \left(11{\cdot}5 + \sqrt{\frac{562{,}500}{S R} + 132{\cdot}25}\right) \qquad (3)$$

which is an expression, in terms of the tidal range and of the area of the tidal basin, for the cross-sectional area required for a propagation of the tidal wave with undiminished range.

Solving equation (2) for S, we obtain

$$S = \frac{A^2}{R\,(23\,A + 562{,}500)} \qquad (4)$$

which gives the superficial area of tidal basin above a point lying on a stretch of river on which the tidal range undergoes no change. It should be borne in mind that while the units of A and of R in these equations are square feet and feet, respectively, the unit of S is 1,000,000 square feet.

The practical bearing of equations (3) and (4) is obvious. By means of them, within certain limits, we can decide the question as to which way the tidal range will be affected by contemplated works of improvement.

Supposing, for instance, the construction of training walls was contemplated at the mouth of the Clyde, five and one-fourth miles below Dumbarton Castle, then the fact would have to be considered that at present a tidal range of ten feet passes undiminished up the river. In order not to let the proposed training walls exercise an unfavorable influence on this present state of affairs, the opening between them, according to equation (3), should not be smaller than

$$A = 350 \times 10\,(11{\cdot}5 + \sqrt{\frac{562{,}500}{350 \times 10} + 132{\cdot}25})$$

$$= 100{,}700 \text{ square feet}$$

Formula (3) can be applied in such cases also where the mean range does not remain constant on the river stretch in question. From the results found for Savannah River, it seems probable that in all such cases another height of range can be found which passes up the same stretch unchanged, unless, indeed, the changes experienced by the

mean range on this stretch are very great. In cases of *decrease* of mean range, this constant range will be *smaller* than the same; in cases of *increase* of mean range, it will be *greater*.

The meagre data that were available for this discussion are not sufficient to let the results appear as exhaustive, and the writer's exertions towards the collection of additional data will, therefore, be continued. If he succeeds to collect a sufficient amount of these, then it will probably be possible to construct on the diagram, besides the curve of "no change of range," curves of uniform increase and decrease, so that mathematical expressions can also be found for those cases in which the tidal range increases or decreases.

(1) HUDSON.

Locality.	*Distance from Mouth. Nautical Miles.*	*S Millions Square Feet.*	*Mean A of Stretch. Square Feet.*	*R Feet.*	*Mean C of Stretch.*	*Change of Range per 10 Miles and per Foot of Range.*
Sandy Hook, . . .	0	8326·4		4·70		
Battery, ...	14	3726·4		4·40		
			170,000		14·3	— 0·10
Sing Sing, ...	42	2580·4		3·30		
			151,300		26·6	no change
Rondout, ...	92	1217·2		3·30		
Tivoli, ...	102	940·5		3·35		
			72,000		26·9	— 0·05
Catskill, ...	112	717·3		3·20		
Albany, ...	139·5			2·30		

(2) DELAWARE.

Cape Henlopen, .	0	20995		4·5		
			2,430,000		31·6	+ 0·14
Egg Island Light, .	20	8233		6·0		
			548,000		27·2	no change
New Castle Range,	55	1549		6·0		
			139,200		26·6	no change
Big Timber Creek,	82	495·3		6·0		
			75,000		30·6	no change
Five Mile Point, .	90	316·6		6·0		
			45,300		34·4	— 0·03
Burlington, . . .	102	167·0		5·8		
			17,600		36·5	— 0·27
Trenton, ...	114·5			4·1		

(3) ELBE.

Locality.	*Distance from mouth, Nautical Miles.*	*S Millions Square Feet.*	*Mean A of Stretch. Square Feet.*	*R Feet.*	*Mean C of Stretch.*	*Change of Range per 10 Miles and per Foot of Range.*
Schaarhorn, . . .	0			9·4		
Brunsbuettel, . . .	27·2	1982		9·1		
			206,000		22·1	— 0·01
Luehe, ...	55·3	432		8·9		
			65,000		26·3	— 0·31
Hamburg, ...	67·2	208		6·2		
			19,000		57·0	— 1·10*
Elbstorf, ...	85·2			0		

(4) CLYDE.

Mouth, ...	0			9·7		
Dumbarton Castle,	5·25	103·6		10·0		
			26,700		43·7	no change
Dalmuir Works, .	10·0	29·8		10·0		
			8,150		92·0	+ 0·13
Glasgow Bridge, .	17·4			11·0		

(5) RARITAN.

Sandy Hook, . . .	0			4·70		
South Amboy, . .	12·0	104·7		4·83		
			28,700		108·6	+ 0·14
French's Landing,	17·0	18·9		5·19		
			6,500		112·4	no change
New Brunswick, .	22·5			5·16		

(6) SAVANNAH RIVER AT MEAN RANGE.

Mouth, ...	0			7·0		
Lower end Long Island, ...	4·6	407		7·0		
			62,250		27·7	— 0·08
Lower end Wrecks Channel, . . .	11·6	160		6·6		
			14,500		18·2	— 0·62
Read's Mill, . . .	16·6	124		4·84		
Head of tide, . . .	38·4			0		

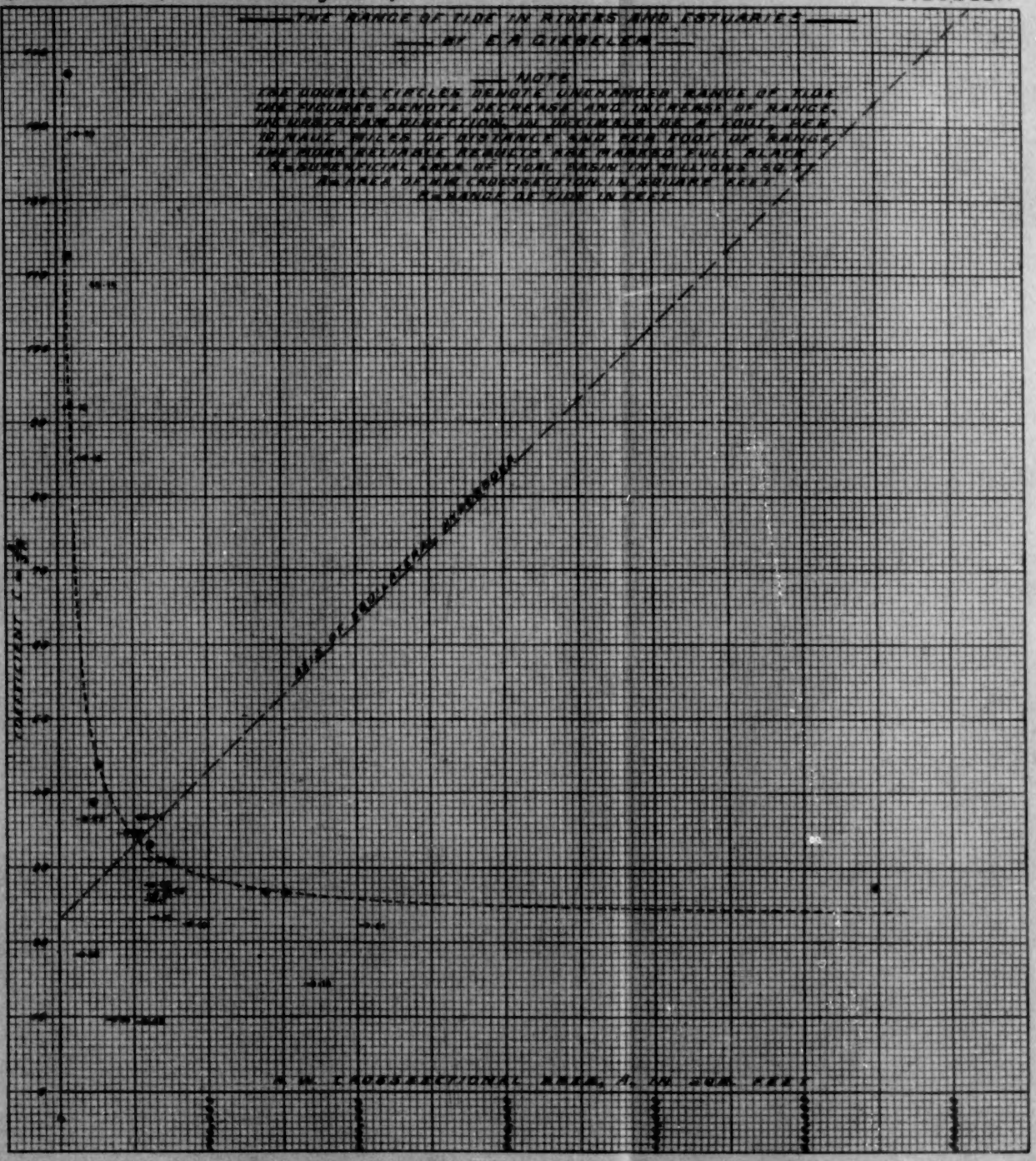
(6*a*) SAVANNAH RIVER AT LOW RANGES.

Lower end Long Island, ...	4·6	407		4·66		
			58,200		36·8	+ 0·05
Fort Oglethorpe, .	11·4	260		4·81		
Lower end Long Island, ...	4·6	407		5·5		
			60,200		33·0	no change
Fort Oglethorpe, .	11·4	260		5·5		
Lower end Long Island, ...	4·6	407		6·02		
			60,700		31·0	— 0·03
Fort Oglethorpe, .	11·4	260		5·91		

(6*b*) SAVANNAH RIVER AT HIGH RANGES.

Locality.	*Distance from Mouth. Nautical Miles.*	*S Millions Square Feet.*	*Mean A of Stretch. Square Feet.*	*R Feet.*	*Mean C of Stretch.*	*Change of Range per 10 Miles and per Foot of Range.*
Lower end Long Island, ...	4·6	407		7·71		
			62,950		25·5	— 0·11
Fort Oglethorpe, .	11·4	260		7·16		
Lower end Long Island, ...	4·6	407		8·89		
			64,750		23·2	— 0·17
Fort Oglethorpe, .	11·4	260		7·94		
		(7) WESER.				
Bremerhafen, . .	0	641·4		10·8		
			88,100		22·2	— 0·19
Elsfleth, ...	18·5	180·0		9·0		
			19,600		32·0	— 1·15*
Vegesack, . . .	27·2	55·5		3·0		
			6,500		141·0	— 2·28*
Hasenbueren, . .	31·8	21·7		0·9		
Bremen, ...	37·3			0		
		(8) SEINE.				
Le Havre, . . .	0					
La Risle, ...	10·8	484		14·50		
			36,150		9·7	— 0·33
La Malleraye, . .	34·0	293		6·40		
Duclair, ...	47·5	210·4		5·12		
			24,000		38·7	no change
Rouen, ...	66·4	81·3		5·22		
St. Aubain, . . .	80·4			3·21		
		(9) NANSEMOND.				
Newman's Point,	0	129·5		3·01		
			14,300		129	+ 0·19
Suffolk, ...	12·1			3·78		
		(10) JAMES RIVER.				
Mouth, ...	0	144·7		2·90		
			19,500		85·2	+ 0·10
Willis Wharf, . .	18·8	33·3		3·50		
			9,450		137·1	no change
Brewery, ...	27·9			3·50		

* Influence of upper slope perceptible.


THE RANGE OF TIDE IN RIVERS AND ESTUARIES
BY E. A. GIESELER
NOTE
THE BOLDFACE CIRCLES DENOTE UNCHANGED RANGE OF TIDE
THE FIGURES DENOTE DECREASE AND INCREASE OF RANGE.
IN CUBIC FEET PER SECOND, IN DECIMALS OF A FOOT PER
MILE OF DISTANCE AND PER FOOT OF RANGE.
THE MORE RELIABLE RESULTS ARE MARKED FULL BLACK.
A = SUPERFICIAL AREA OF TIDAL BASIN IN MILLIONS SQ. FT.
a = AREA OF MIN. CROSS-SECTION IN SQUARE FEET
R = RANGE OF TIDE IN FEET.
COEFFICIENT C =
MEAN CROSS-SECTIONAL AREA, A, IN SQUARE FEET.

(11) ST. JOHN'S.

Locality.	*Distance from Mouth. Nautical Miles.*	*S Millions Square Feet.*	*Mean A of Stretch. Square Feet.*	*R Feet.*	*Mean C of Stretch.*	*Change of Range per 10 Miles and per Foot of Range.*
Mouth, ...	0			4·6		
Mayport Mills, . .	1·5	4172		4·3		
			57,500		9·3	— 0·68
Jacksonville, . . .	19·8	3540		1·0		
			130,000		31· (?)	
Black Point, . . .	26·2	3164				
			140,000		70 (?)	
San Patricio, . . .	41·9	2028				
			125,000		160 (?)	
Tocoi, ...	57·5	941				
			90,000		250 (?)	
Palatka, ...	73·2	237				
Georgetown, . . .	95·8					

The coëfficients of St. John's River above Jacksonville are approximate only, because *R* is not known; their rapid increase, however, cannot be doubted, and makes it probable that somewhere above Black Point an increase of range takes place.

NEW ALLOYS AND THEIR ENGINEERING APPLICATIONS.

BY F. LYNWOOD GARRISON.

[*A lecture delivered before the Franklin Institute, January 30, 1890, and February 6, 1891.*]

[*Continued from p. 65.*]

Aluminum Steel.—The effect of aluminum upon the properties of iron and steel is a subject upon which there is much difference of opinion amongst metallurgists. It will suffice, however, for our present purposes to merely call attention to a few fairly well-established facts on the subject. The use of ferro-aluminum and aluminum steel in the arts is quite new, and it can hardly be said we know much of their properties and peculiarities. According to the results of a series of experiments recently made by Mr. James Riley, at the works of the steel company of Scotland.*

* *Journal of the Iron and Steel Institute*, No. 1, 1890, p. 167.

It seems "that the addition of aluminum slightly increases the breaking strain, and proportionately the elastic limit in rolled and cast steel, according to the amount added, up to not more than one per cent., when further additions do no more good." (See Table 1.)

It also somewhat improves the extension in rolled steel, but after 0·5 per cent. is passed each addition of aluminum reduces extensibility. Its addition is useful, because of a greater fluidity of the steel, where castings of comparatively thin metal are to be run. On the other hand, contraction cracks are more liable to occur, unless the temperature of the castings be kept low.

Until quite recently, there seemed to be a general impression amongst metallurgists that the addition of aluminum, either the metal itself or in the form of a mixture of cast iron and aluminum (ferro-aluminum), to low carbon iron or to steel had the effect of lowering the fusing point of the metal. This statement has by no means been proved or disproved.

In February, 1886, at the meeting of the American Institute of Mining Engineers in Pittsburgh, Mr. Petter Ostberg, of Stockholm, Sweden, exhibited specimens of exceptionally good malleable iron (mitis) castings, which he claimed were produced from wrought iron or steel. He says, in his paper,* "We heat the wrought iron just to melting, but not more; and as soon as molten, we add from 0·05 to 0·1 per cent. aluminum, thereby producing a sudden lowering of the melting point." Recent investigations, however, have shown this statement to be open to question, as it is a well-known fact that ordinary steel sometimes contains small quantities of aluminum without having its melting point affected. Mr. Howe states that the most careful chemists have never succeeded in detecting aluminum in in these mitis castings.†

Analyses of Mitis, by Dr. Edward Riley, show as an average of seven samples: carbon, 0·099; silicon, 0·100; phos-

* *Trans. of the Am. Inst. of Mining Engineers*, vol. xiv, p. 777.

† Howe's *Metallurgy of Steel*, pp. 88, 130.

ALUMINUM STEEL.

TABLE I.—TENSILE TESTS OF ANNEALED AND UNANNEALED BARS; ALSO SPECIFIC GRAVITY, FORGING, WELDING AND BENDING TESTS. *Hadfield.*

Series and Mark Referred to in Paper.	Analysis Per Cent.								Specific Gravity.	Drillings taken from.	How Ingot Forged.	Whether Tested in Annealed or Unannealed Condition.	Original Diameter in Inches.	Original Area in Inches.	Limit of Elasticity in Tons per Sq. Inch.	Amount of Stretch in Inches at Elastic Limit.	Breaking Load in Tons per Square Inch on Original Area.	Extension Measured in a Length of — Inches.	Total Extension, Per Cent.	Reduction of Area, Per Cent.	Appearance of Fracture of Test Bar.	Appearance of Fracture of Annealed Forged Bar from which Test Bar was Prepared.	Bending Tests of Annealed Forged Bars, 11-16 Inch Wide by ½ Inch Thick.	Welding Tests.
	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Aluminum.	Calculated Percentage of Aluminum.	Loss (Approx.) Per Cent. of Aluminum.																
1167	·22	·09	—	—	·07	·15	·25	·10	—	Ingot.	Very well.	Unannealed.	·7979	·50	21·00	—	29·00	2	36·70	62·9	Granular; very dark; a little roaked; smooth on outside.			
1167	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	20·0	—	25·00	2	41·30	63·62	Dark granular; a little roaked; smooth on outside.	Close fine granular.	Bent double cold.	
1167 A	·15	·28	·10	·04	·18	·38	·50	·12	—	Ingot.	Fairly well.	Unannealed.	·7979	·50	23·0	—	30·8	2	37·85	58·28	Dark granular.			
1167 A	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	20·0	—	26·0	2	40·35	60·74	Dark granular; smooth on outside.	Close fine granular.	Bent double cold.	
1167 B	·20	·12	—	—	·11	·61	·75	·14	7·781	Ingot.	Rather shelly.	Unannealed.	·7979	·50	21·50	—	28·0	2	38·40	54·50	Dark granular; several specks in body.			Would not weld.
1167 B	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	18·0	—	25·50	2	40·50	61·98	Dark granular; rough on outside.	Fine close granular; much closer before annealing.	Bent double cold.	
1167 C	·18	·16	·09	·03	·14	·66	1·00	·34	—	Ingot.	Very well.	Unannealed.	·7979	·50	20·50	—	29·0	2	33·35	49·86	Dark granular; several long specks in body.			
1167 C	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	18·0	—	27·0	2	33·0	52·14	Dark granular; rough on outside.	Fine grain.	Bent double cold.	
1167 D	·17	·10	—	—	·18	·72	1·25	·53	7·755	Ingot	Very well.	Unannealed.	·7979	·50	22·0	—	28·0	2	40·0	60·74	Dark granular.			Would not weld.
1167 D	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	18·0	—	25·0	2	47·10	64·86	Dark granular; smooth on outside.	Fine close grain; much closer before annealing.	Bent double cold.	
1167 E	·26	·15	·08	·04	·11	1·16	1·50	·34	—	Ingot.	Very well.	Unannealed.	·7979	·50	23·0	—	33·0	2	32·05	51·46	Dark fine granular; smooth on outside.			
1167 E	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	21·0	—	29·0	2	34·40	53·02	Dark granular; smooth on outside.	Fine grain.	Bent double cold.	
1167 F	·21	·18	—	—	·18	1·60	2·00	·40	7·6237	Ingot.	Rather shelly.	Unannealed.	·7979	·50	20·0	—	31·0	2	32·70	52·14	Dark granular; rough on outside.			
1167 F	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	13·0	—	26·0	2	36·35	67·06	Dark granular; rough on outside.	Coarser.	Bent double cold.	
1167 G	·21	·18	·09	·03	·18	2·20	2·50	·30	—	Ingot.	Fairly sound	Unannealed.	·7979	·50	21·0	·0280	31·0	2	22·75	27·80	Crystalline, rather coarse.			Would not weld.
1167 G	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	19·0	·0095	28·0	2	34·87	47·12	Dark granular; fibrous; very rough on outside.	Coarser.	Bent double cold.	
1167 H	·24	·18	—	—	·32	2·24	3·50	1·26	7·554	Ingot.	Fairly well	Unannealed.	·7979	·50	21·50	·0085	32·50	2	20·67	24·64	80 per cent. outer circle, crystalline; 20 per cent. inner circle, finer crystalline; rather coarse.			
1167 H	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	18·50	·0133	28·50	2	33·02	48·62	Dark granular; fibrous.	Coarser.	Bent double cold.	
1167 I	·22	·20	·08	·03	·22	5·60	6·00	·40	—	Ingot.	Very shelly.	Unannealed.	·7979	·50	None visible.	—	38·0	2	3·67	3·96	Crystalline; lustrous; broke in radius.			
1167 I	—	—	—	—	—	—	—	—	—	—	—	Annealed.	·7979	·50	27·00	·0050	36·0	2	6·45	6·16	Crystalline; lustrous; broke in radius.	Coarse.	16° Broken.	
1167 J	·26	·33	·08	·03	·25	9·14	10·00	·86	6·6726	Ingot.	Would not forge.	—	No test bar made; would not forge.										Would not forge.	

phorus, 0·153, and manganese, 0·022 per cent. No aluminum was found in this metal. It will be noticed that the above average of elements is about the same as the analysis of ordinary wrought iron with the slag removed. The silicon and manganese are a little high.* The fact is, the fluidity of this metal and its excellence for castings is, perhaps, as much due to the other elements present in the metal and to the peculiar method of melting it, as to the minute quantity of aluminum added.

Omitting from consideration the action of aluminum on cast iron, we find, according to Keep's researches, that the general effect of aluminum (or ferro-aluminum) when added to molten non-carburetted iron just before teeming, is quieting. This action is very marked, and is more sudden than that of ferro-silicon

While the addition of ferro-aluminum makes non-carburetted iron more fluid (but it does not necessarily follow the fusing point has been lowered), it does not seem to act in same way on steel with over 0·25 per cent. carbon. When the carbon point exceeds this it appears to decrease rather than increase the fluidity.

Without special additions, non-carburetted iron usually evolves gases so copiously in setting that its castings are porous. The action of the aluminum is probably to unite with and to remove the oxygen present in the steel in one form or another; as is especially the case with cold blown steel.

In summing up his work on aluminum in carbonized iron, Keep observes† that in whatever way the end is accomplished, aluminum seemed to permit good castings to be made from metal which could not be otherwise used alone. This remark applies more particularly to cast iron (carburetted) and to steel.

Keep also states,‡ that presence of 0·20 per cent. aluminum makes the grain of ingot iron (mild steel?) close and uniform, removes blowholes, increases the ultimate strength

* Keep, *Trans. of the Am. Inst. of Mining Engs.*, vol. xviii, p. 838.

† *Journal of the Iron and Steel Inst.*, No. 1, 1890, p. 132.

‡ *Trans. of the Am. Inst. of Mining Engineers*, vol. xviii, p. 835.

fifty per cent., but diminishes the viscosity or tendency to flow. Power to resist shock is almost doubled.

According to Mr. R. A. Hadfield,* it is doubtful whether aluminum increases the fluidity of properly-made steel, but if it does, the apparent increase or evolution of heat seems far more likely to account for any increase of fluidity that may occur rather than to the so-called lowering of the melting point.

As the aluminum increases to large amounts, say above ·50 per cent., the metal becomes quite thick, "creamy," and sets quickly. No doubt this is partly caused by a considerable portion of the aluminum being oxidized to alumina and becoming entangled as slag, in the same way as occurs when silicon is oxidized to silica. Unless suitable flux is present, this excess of oxide cannot be carried off, the molten metal becomes less fluid, and causes the "thickness" noticed. There is a resemblance in this respect to the action of high percentages of silicon added to iron. When exceeding about ·75 per cent. aluminum, the molten material so rapidly "creams over" on the surface, that the production of sand-moulded articles is only effected with difficulty; in fact, it was only by using considerable care that the cast test bars were obtained.† It must not be overlooked that Mr. Hadfield is here referring to comparatively high percentages. So far as his own experiments have gone, aluminum, as regards lower percentages, also acts in a similar manner to silicon under the same circumstances.

It does not appear from Hadfield's experiments that the addition of aluminum improves the soundness of castings any more than does silicon, manganese, or silicon combined with manganese. It seems, however, that more aluminum may be present in cast material than silicon in cast silicon-steel before brittleness sets in.

After reaching the region of brittleness, and by adding still higher percentages of aluminum, there is no return of

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* *Journal of the Iron and Steel Inst.*, No. II, 1890, p. 171

† Mr. Keep, even with cast iron, found a decided decrease in fluidity by the addition of aluminum.

strength—on the contrary; so that this material in no way resembles the curious properly noted in this respect with regard to manganese steel.

The gradual increase of aluminum is very clearly shown to reduce the toughness both of unannealed and annealed specimens.

As might be expected from the soft nature of the metal aluminum, its addition to iron does not add materially to the hardness, again in this respect resembling the effect of silicon. Seven to eight per cent. cast aluminum steel may be readily drilled and filed.

Hadfield considers that the action of aluminum may be classed along with that of silicon, sulphur, phosphorus, arsenic and copper, as giving no increase of hardness to iron, in contradistinction to carbon, manganese, chromium, tungsten and nickel. Water-quenching upon either forged or cast aluminum steel seems to produce no effect.

Here again we have another addition to the list of elements which, alloyed with iron, do not produce "water-quenched hardness," if the term may be allowed. In fact, notwithstanding that manganese, chromium, tungsten and nickel do impart a certain and considerable kind of hardness to iron, either in the cast or forged state, carbon retains its position as being the only element which confers upon iron the property of becoming hard by water-quenching. In steel, made with the hard metals just mentioned, if the carbon present be low, no matter at what heat they are water-quenched, the characteristic hardness of carbon steel, such as scratching glass or forming the edge of a cutting tool, is wanting.*

As regards malleability, as much as 5·60 per cent. aluminum may be present in the steel before malleability ceases. This is about the same limit as in the silicon steel described by Hadfield.

Comparing (Table I) the sample of aluminum steel containing 1·6 per cent. aluminum and ·12 per cent. carbon, with silicon steel of 1·60 per cent. silicon and ·19 per cent.

* Hadfield, *Jour. Iron and Steel Inst.*, No. II, 1890, p. 180.

carbon,* the former has an advantage in elongation of one per cent. A characteristic of the aluminum steel is that the reduction in area is greater; in this respect it seems to resemble chrome steel. There is, however, considerable difference in the tensile strength of the two alloys, the aluminum steel being several tons less. The same remark applies to the permanent set point, which in the annealed aluminum steels is fairly low. Numerous comparisons might be drawn between the two steels, especially as the test bars in both series of experiments were exactly the same in length and section, and were treated on all points similarly. Reference to the diagrams and tables in each case will be found of interest. One difference clearly brought out is, that the tensile strength of iron is not increased so much by an addition of aluminum as of silicon.

It has been stated that very small percentages of aluminum considerably raise the limit of elasticity. It will be seen from the table of tests, and specially from the two almost carbonless samples, just quoted, that this increase is slight, if any, as compared with ordinary steel, and also that aluminum does not raise the elastic limit so much as silicon.†

Aluminum causes the tough percentages, both in the cast and forged material, to break with dark fibrous fracture, similar to wrought iron of good quality, only much darker in color. This appearance in some of the specimens is very curious, as small patches of bright fine crystals are to be seen surrounded by a remainder of black and dark fibrous material.‡

Hadfield has always found that these special steels or alloys, such as silicon, manganese or chromium steel have but slight, if any, welding properties.

Speaking generally of the application of aluminum to the manufacture of iron and steel, the usual amount stated to be requisite for producing good results is about ·10 per cent.; but in many cases this would be too little.

* See table under silicon steel.

† Hadfield, *Jour. Iron and Steel Inst.*, No. II, 1890, p. 178.

‡ *Ibid.*, p. 180.

The chief obstacle to the extensive use of aluminum in this particular is its comparatively high cost. If aluminum can eventually be brought to compete in price with existing alloys, it may find use for certain special purposes such as in higher carbon-steel where, according to Hadfield, silicon does not seem to act so powerfully in producing soundness, as in the case of milder steel with carbon ·50 per cent. and under.

Therefore, whilst for some special purposes aluminum may be employed in the manufacture of iron, at any rate with our present knowledge of its properties, this use cannot be large, especially when taking into consideration the fact of its comparatively high price. Its special advantage seems to be that it combines in itself the advantages of both silicon and manganese; but so long as alloys containing these metals are so cheap and aluminum dear, its extensive use seems hardly probable.*

Chrome Steel.—Chromium increases the hardness of iron, perhaps also the tensile strength and elastic limit, but it lessens its weldibility.

Ferro-chrome, according to Berthier,* is made by strongly heating the mixed oxides of iron and chromium in brasqued crucibles, adding powdered charcoal if the oxide of chromium is in excess, and fluxes to scorify the earthy matter and prevent oxidation.

This, according to Howe,† is substantially the method employed at Brooklyn, N. Y., and at the Unieux Works in France, where chrome steel has been produced in large amounts for a number of years. Chrome steel is easily made from ferro-chrome by simply melting it with wrought iron or steel in graphite crucibles.

Up to the present time the best available data regarding chrome steel are rather contradictory. In this as in all the other steel alloys, the physical properties vary greatly, according to the relative proportions of the other elements present in the alloy.

* Hadfield, *Jour. Iron and Steel Inst.*, No. II, 1890, p. 181.
* *Annales des Mines*, 1st ser., vi., p. 573.
† *Metallurgy of Steel*, p. 75.

In general, it may be considered that chromium has the tendency to harden steel. This, however, is by no means a general rule, as this hardening property may in great degree depend upon the relations and proportions of the other elements present.

In most cases chromium increases somewhat the tensile strength and elastic limit of steel. Its ductility, according to Howe,* when subjected to elongation, is not necessarily increased. Mr. Howe also states the same is true when the alloy is subjected to shock. The Holtzer Company (Unieux, France,) have, however, for a number of years been making remarkably hard and tough projectiles with chrome steel.

It is said unhardened chrome steels are somewhat harder and more difficult to cut than chromeless steels of like carbon content,† and their hardness increases with the percentage of chromium.

Chromium does not appear to give steel the power of becoming harder when quenched or chilled.

Howe‡ states that chrome steels forge more readily than tungsten steels, and when not containing over 0·5 of chromium nearly as well as ordinary carbon steels of like percentage of carbon.

Chrome steel is not easily welded, owing to the difficulty of scorifying off the scale of oxide. This difficulty probably increases with the content of chromium. Chrome steel has the great advantage of cheapness, and for steel projectiles and some special purposes has given some excellent results.

On the whole, however, the status of chrome steel is not satisfactory. There are other steel alloys coming into use, which are so much better, that it would seem to be only a question of time when it will drop entirely out of the race.

Howe§ states that many experienced chemists have found no chromium, or but the merest traces, in chrome

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* *Metallurgy of Steel*, p. 77.

† *Ibid.*, p. 77.

‡ *Ibid.*, p. 78.

§ *Ibid.*, p. 79.

TABLE II.—CHROME STEEL. *Howe.*

Number.	Observer, Source, etc.	Composition. Chromium.	Combined Carbon.	Graphite.	Manganese.	Silicon.	Tungsten.	Physical Properties. Tensile Strength. Pounds per Square Inch.	Elasit Limit. Pounds per Square Inch.	Elongation. Per Cent.	Elongation. Inch.	Reduction of Area Per Cent.	Bent Before Breaking. Degrees.	Diameter of Piece. Inches.
1	Unieux, unhardened, Brustlein,	4·	1·10	—	—	—	—	177,800	177,000 ±	7·5	—	—	—	—
1·5	Faraday and Stodart; very hard, extremely malleable,	2·9 ±	1· ?	—	—	—	—	—	—	—	—	—	—	—
2	Unieux, unhardened, same steel,	2·2	0·6	—	—	—	—	103,000	67,500	19·	—	67·+	—	—
3	" annealed after oil hardening, Brustlein,	2·2	0·6	—	—	—	—	199,000	199,000	3·	—	—	—	—
4	" Brustlein,	1·2	·34	—	—	—	—	88,180	53,300	7·	—	—	—	—
4·5	Faraday and Stodart; hard, forged well,	·99 ±	1· ?	—	—	—	—	—	—	—	—	—	—	—
5	A. A. Blair and D. Smith, P,	·45 @ ·92	·84 @ 1·19	·01 @ ·03	·03	1·28	—	115,922	—	—	—	—	—	—
6	" " F,	·22 @ ·64	·81 @ ·99	·01 @ ·02	—	—	—	104,735	—	—	—	—	—	—
7	Brooklyn Adamantine, Hunt and Clapp and the author,	·53	1·03	—	·17	·05	—	157,000 *a*	—	0·6	4″	0·	2·5	·53 octagon.
8	Döhlen, Ledebur,	·50	·91	—	—	—	—	116,000 *b*	—	0·6	4″	0·	15·5	·53 "
9	Brooklyn very hard, Hunt and Clapp and the author,	·38	·90	—	1·89	·03	·98	122,300	—	15·7	—	—	—	—
9·5	A. A. Blair and D. Smith, G,	·38	·84	·01	·22	·09	—	134,000	—	2·	4″	8·	40·	·43 square.
10	Brooklyn, St. Louis Bridge (?) Blair,	·38	·94	—	—	—	—	110,572	—	—	—	—	—	—
11	" " " (?) "	·36	·98	—	—	—	—	—	—	—	—	—	—	—
12	" Hunt and Clapp and the author,	·29	1·32	—	·15	·15	·73	—	—	—	—	—	—	—
13	" 1A, " " " "	·25	·70	—	—	—	—	124,000 *a*	—	6·	3·5″	4·	1·5	·63 rounds.
14	" St. Louis Bridge (?) Blair,	·0	·60	—	—	—	—	127,000 *b*	—	9·	3·5″	2·	5·5	·63 "
15	" " " (?) "	·0	·31	—	—	—	—	145,400	—	5·5	—	19·	25· *a*	—
16	Unieux, unhardened,	—	—	—	—	—	—	—	—	—	—	—	30· *c*	—
17	" quenched from yellow,	—	—	—	—	—	—	—	—	—	—	—	—	—
18	" " " bright cherry, same bar, Barbier, Boussingault,	—	—	—	—	—	—	108,700	83,446	15·	—	50·	60·	·86 octagon.
19	" " " cherry,	—	—	—	—	—	—	191,000	—	1·2	—	2·	—	—
20	" " " dark red,	—	—	—	—	—	—	202,900	—	2·	—	6·	—	—
21	Brooklyn, West Point test, strongest bar,	—	—	—	—	—	—	104,260	62,306	14·	—	63·	—	—
22	" " weakest "	—	—	—	—	—	—	100,000	55,000	17·	—	63·	—	—
23	" Kirkaldy's test,	—	—	—	—	—	—	187,915	—	—	—	—	—	—
24	" "	—	—	—	—	—	—	168,765	—	—	—	—	—	—
25	" "	—	—	—	—	—	—	166,360	87,000	7·6	—	30·	—	—
26	" "	—	—	—	—	—	—	129,630	71,000	6·2	—	59·	—	—
27	Unieux, private communication,	—	—	—	—	—	—	126,870	63,000	7·2	—	59·	—	—
28	" " "	—	—	—	—	—	—	124,390	54,000	11·	—	47·	—	—
29	" annealed, same bar,	—	·7 ±	—	—	—	—	157,600	—	—	—	57·	—	—
30	" oil hardened and annealed, Brustlein,	—	·7 ±	—	—	—	—	152,200	—	—	—	57·	—	—
31	Brooklyn, Thurston,	1·04	·63	·01	·05	·15	—	102,200	59,300	19·5	3″	68·	—	—
32	" "	·92	·44	·01	·02	·14	—	213,300	199,000	6·2	3″	29·2	—	—
33	" "	·61	·46	·0	·03	·12	—	—	—	—	—	—	—	—
								—	—	—	—	—	—	—

1. Unhardened, Unieux. 1·5. Faraday and Stodart. Forged well, with no disposition to crack: hard, as malleable as pure iron, gave a very fine damask. The composition here given is inferred from their statements that they melted together 1,600 grs. of steel, whose carbon is roughly assumed at 1 per cent., and 48 grs. of pure chromium; and further that "in all the experiments made in the laboratory the button produced was weighed, and if it fell short of the weight of both metals put into the crucible it was rejected as imperfect." *Phil. Trans. Royal Soc.*, 1822, pp. 267, 258. 2 and 3. Unieux, 2 unhardened, 3 the same steel annealed from bright redness after oil-hardening. 4. Unieux. 4·5, Faraday and Stodart, *loc. cit.*, good, forged well, with no disposition to crack: hard, but not so hard as No. 1·5. The remarks concerning No. 1·5 apply to No. 4·5, *mutatis mutandis*. 5 and 6. *Repl. of U. S. Bd. to Test Iron*, etc., II, p. 590. Thurston, *Mat'ls of Engineering*, II, p. 424. 7. Brooklyn "Adamantine" chrome steel, *a*, unhardened, *b*, quenched in oil from dull redness. Hunt and Clapp and Howe. 8. Döhlen, *Ledebur*, *Handbuch*, p. 261. 9. One of the hardest brands of Brooklyn chrome steel, Hunt and Clapp and Howe. 9·5. *Rept. U. S. to Test Iron*, II, p. 590. 10 and 11. A. A. Blair. Said to be from struts of St. Louis Bridge: private communication, Mr. Howe, May 30, 1887. 12 and 13. Brooklyn chrome steel. Hunt and Clapp and Howe. 13 is styled "No. 1A." *a*, Unhardened: *b*, hardened in oil from dull redness. 14 and 15. Brooklyn (?) chrome steel, said to be from struts of St. Louis Bridge. A. A. Blair, private communication, May 30, 1887. 16 to 20. Unieux. 16, hardened; 17, quenched from yellow; 18, from bright cherry; 19, from cherry; 20, from dark red (sombre). 21 strongest, and 22 weakest of three bars of Brooklyn chrome steel tested at West Point foundry. No. 21, in two trials, gave 176,920 and 198,910 pounds and after being heated, 168,530 and 193,210 pounds tensile strength; No. 22, in the same way, gave before heating 173,770 and 163,760 pounds and after heating 174,540 and 190,910 pounds, tensile strength per square inch. 23 to 26. Kirkaldy, circular of Brooklyn Chrome Steel Co. 27, 28. Unieux. Private communication from J. Holtzer et Cie. 29, 30. Unieux: 29, annealed; 30, oil-quenched, and annealed from dark redness. 31 to 33. Brooklyn, Thurston, *Mat'ls of Engineering*, II, p. 307.

UNIEUX STEELS.—Excepting Nos. 27, 28, and 31 to 33, described by Brustlein and Boussingault, *Ann. de Chim. et Phys.*, 5th Ser., XV, and *Jour. Iron and St. Inst.*, 1886, II, p. 809.

BROOKLYN CHROME STEELS.—Nos. 7, 9, 12 and 13, obtained by Howe from the makers or their Boston agents, and tested by him. In the bending tests, these steels were held firmly in a vise and struck with moderate force with a sledge till they broke. The bending was measured after fracture.

a. As received from the makers. *b*. After quenching in oil from dull redness. *c*. After annealing from cherry redness.

TABLE III.—PHYSICAL PROPERTIES OF CHROME STEEL AND TUNGSTO-CHROME STEEL. *Holtzer and others.*

Number.	Tensile Strength. Pounds per Sq. In.			Elastic Limit. Pounds per Square Inch.			Elongation. Per Cent. in 7·9 Inches.			Contraction of Area. Per Cent.		
	Natural State.	Oil-hardened and Tempered	Oil-hardened and Annealed.	Natural State.	Oil-hardened and Tempered	Oil-hardened and Annealed.	Natural State.	Oil-hardened and Tempered	Oil-hardened and Annealed.	Natural State.	Oil-hardened and Tempered	Oil-hardened and Annealed.
1	156,877	—	—	—	—	—	9·5	—	—	54·5	—	—
	—	199,017	—	—	152,184	—	—	8	—	—	43	—
	—	—	104,538	—	—	63,575	—	—	19·5	—	—	63
2	109,230	—	—	64,571	—	—	18·3	—	—	59	—	—
	—	195,421	—	—	—	—	—	6	—	—	30·5	—
	—	—	136,112	—	—	118,760	—	—	13	—	—	58·1
3	93,443	—	—	55,753	—	—	22·5	—	—	38·5	—	—
	—	212,772	—	—	—	—	—	0·5	—	—	0	—
	—	—	124,592	—	—	109,230	—	—	6	—	—	17·5
4	94,439	—	—	55,753	—	—	26·5	—	—	50·5	—	—
	—	172,949	—	—	159,580	—	—	6·5	—	—	26	—
	—	—	122,600	—	—	106,386	—	—	12·2	—	—	30
5	95,292	—	—	56,749	—	—	20·8	—	—	30	—	—
	—	204,096	—	—	190,017	—	—	2·5	—	—	6	—
	—	—	116,769	—	—	104,538	—	—	7	—	—	33
6	103,115	—	—	65,425	—	—	17·5	—	—	33	—	—
	—	212,772	—	—	193,430	—	—	1·8	—	—	7	—
	—	—	137,107	—	—	123,596	—	—	6·2	—	—	15
7	114,635	—	—	72,251	—	—	14·5	—	—	24	—	—
	—	210,497	—	—	189,163	—	—	—	—	—	—	—
	—	—	148,201	—	—	133,409	—	—	5	—	—	13
8	142,000 @ 156,000			113,800 @ 128,000			10 @ 12 per cent. in 3·9 inches.			42 @ 45		
9	114,000			68,300			13·52			—		
10	128,000 @ 142,000			—			9 @ 10·2			—		

The "natural state" pieces are simply cooled slowly after forging.

The "oil-hardened and tempered" pieces are quenched in oil from a low yellow heat and slightly reheated.

The "oil-hardened and annealed" pieces are similarly quenched, reheated to very dull redness and cooled slowly.

Nos. 1 to 6 are chrome steels. Nos. 5, 6 and 7 contain both chromium and tungsten. 1 to 8, inclusive, are Holtzer's; 8 is for plates 0·59-inch thick, for the French navy. 9. Railway tire which has resisted 14 blows of a 1-ton ram falling 32 feet 10 inches. St. Chamond. 10. St. Etienne: usual properties of their armor plates 0·16 to 1·18-inch thick.

steel sold in the American and possibly British markets. Considerable amounts of chrome and tungsto-chrome steels are made in France by Holtzer, the St. Etienne and other steel works.

There was a rather extensive exhibit of chrome steel at the Paris Exhibition of 1889. The Holtzer Company (Unieux) use large quantities of it in making thin plates for cuirasses. Some of these thin plates, 0·16-inch thick, hardened and annealed, can then be bent double and hammered close. At the same time it is specified that they must not be penetrated by a lead rifle ball with a velocity of 1,500 feet per second, at a distance of thirty-three feet.*

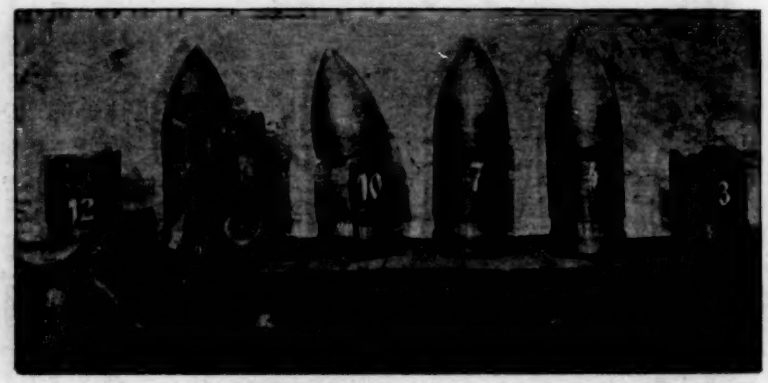

FIG. 5.

It has been stated that the presence of chromium in steel renders it more susceptible to oxidation by exposure to air and moisture than ordinary steel, and that this effect is quite the reverse of the action of tungsten.†

In *Fig. 5* we have shown some of the six-inch Holtzer chrome-steel projectiles (shells) which were used at the now celebrated armor-plate trials at Annapolis, Md., September 18, 1890. Four of these projectiles completely perforated the "compound" plate and lodged in the backing. Two of

* Howe, *Metallurgy of Steel*, p. 367.

† I do not know who is the author of this statement. I have never seen any evidence either to prove or disprove it.

them broke in half on the "nickel-steel" plate, the points sticking in the plate; two others remained in the plate apparently intact. One projectile remained in the "steel" plate, and two penetrated about twelve inches and rebounded entire, another did the same but broke into several pieces.

In *Fig. 6* we have shown the three-eighths inch "Firth armor-piercing shell" used in the same trials.* The first fired against the "nickel-steel" plate broke into fragments; the second completely penetrated the "compound" plate and was recovered entire; the third broke into three large pieces on the "steel" plate.†

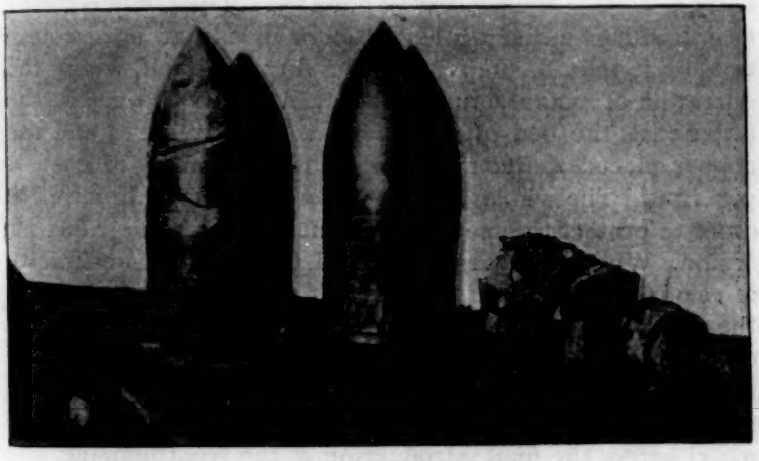

FIG. 6

Copper Steel.—A few years ago M. Henri Schneider, of Creusot, France, took out patents for the manufacture of alloys of iron and copper, and steel and copper. In the patent specifications it is stated the alloy of cast iron and copper can be made in a crucible, cupola, or open-hearth furnace. "The furnace is charged with copper scrap and

* The Firth shells are made by what is termed the Firminy process, which appears to be a secret method of chilling and tempering chrome and tungsten steel projectiles.

† These photographs, and also a number of others of the armor plate, I have received through the courtesy of the Navy Department.

cast iron mixed between layers of coke, or if a cupreous coke be employed then the cast iron is laid in alternate layers with it, and a layer of anthracite is preferably laid over the whole. The alloy thus formed contains, generally, from five to twenty per cent. of copper, according to the purpose for which it is to be employed, and it is remarkable for its great strength, tenacity and malleability—properties which may be still further developed by chilling or tempering."*

The alloy thus formed is charged into the bed of a furnace, with the ordinary ingredients used in the manufacture of steel, preferably under a layer of anthracite, to avoid oxidation. It is important that the copper be introduced at as early a stage in the process as possible. The said alloy may be introduced either while molten or in its hardened condition, or it may be prepared in the furnace itself, where the operation of manufacturing the steel is carried on. In the latter case, the bed of anthracite is first prepared and the copper placed thereon with a suitable quantity of cast or pig iron. The whole is then covered with anthracite, in order to protect the metal from contact with the air during fusion. When the charge is melted, the excess of anthracite is removed and successive charges of iron or scrap added, the operation being then continued in the ordinary way, care being taken to continually protect the bath from oxidation by means of a layer of slag or cinder, which may be renewed as required, and also to prevent red-shortness in the metal before the final introduction of the recarbonizing and manganiferous silico-spiegel iron or ferro-manganese.

The steel produced by this means contains from two to four per cent. of copper.

It is stated in the patent specifications that the steels alloyed with copper are especially useful in the manufacture of ordnance, armor-plate, gun-barrels, projectiles and other military purposes, or in the manufacture of commercial bars, sheets, etc.†

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* U. S. Patent 415,656, Nov. 19, 1889.

† U. S. Patent 415,654, Nov. 19, 1889. The British Patents Nos. 16,568 and 16,569, 1888, seem to have been abandoned in 1890.

The presence of copper in steel was formerly regarded as injurious, tending to cause a red-shortness and a sensible diminution of its tenacity. As a matter of fact, such is generally the case except under certain conditions when its presence seems to be an absolute benefit.

Small amounts of copper (under five per cent.) readily alloy with steel. It is very doubtful if steel will form a perfect alloy with over ten per cent. of copper. Mushet found that although five per cent. of copper formed an apparently homogeneous alloy with steel, when the copper reached ten per cent. minute segregation appeared. When twenty-five per cent. of copper is present, much of it sinks to the bottom of the molten alloy and is found, on cooling, in patches and streaks; with white cast iron, this tendency to segregate is even stronger. It is probably accounted for by the fact that the presence of carbon tends to diminish the union of iron and copper.

Mr. James Riley, of Glasgow, has recorded a very interesting observation on the presence of copper in steel.* "If an alloy of steel and copper be made, and the resultant metal were examined under the microscope, it would be found the copper was not alloyed—it was disseminated all through the piece. If, in making that alloy they used some aluminum, they would find a totally different result—the alloy was perfect."

Copper acts much like sulphur in rendering steel more or less red-short and destroying its welding power. Whether the presence of manganese counteracts this effect of copper like it does that of sulphur is not yet known.†

Mr. Willis, of the Landore Works, in South Wales, found that 0·1 per cent. of copper produced no appreciable effect on the quality of the steel.‡ Wasum§ has shown that an appreciable amount of copper may be present in steel without affecting its quality, so long as there was no notable

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* *Journal of the Iron and Steel Institute*, No. 1, 1890, p. 123.

† Howe's *Metallurgy of Steel*, p. 83.

‡ *Iron*, Vol. 28, p. 539.

§ *Stahl und Eisen*, 1882, p. 193.

amount of sulphur present. According to Choubly* steel of the following composition rolled perfectly well: Carbon, 0·5; phosphorus, 0·15; sulphur, 0·04, and copper, 1·0 per cent.

Ball and Wingham, in their researches on the influence of copper on the tensile strength of steel, give the following as some of their results:†

Test-Piece No.	*Copper. Per Cent.*	*Carbon. Per Cent.*	*Tensile Strength. Pounds per Sq. In.*	*Elongation. Per Cent.*
1, ...	0·847	0·102	40,992	10
2, ...	2·124	0·217	81,984	5
3, ...	3·630	0·380	106,624	5
4, ...	7·171	0·712	125,440	nil

The following tests are of some copper steels exhibited at the Paris Exhibition of 1889, by Messrs. Holtzer, of the Unieux Steel Works.‡ They contained from three to four per cent. of copper.

The exceedingly high elastic limit of the hardened bars should be noted; it is almost equal to the tensile strength, at the same time the elongation is considerable.

No.	*Elastic Limit. Pounds per Sq. In.*	*Tensile Strength. Pounds per Sq. In.*	*Elongation. Per Cent.*
1, ...	43,563	77,761	22·5
2, ...	99,330	109,972	17·5
3, ...	94,789	113,236	13·0
4, ...	65,274	83,721	18·6
5, ...	141,900	173,543	6·2
6, ...	121,324	149,420	11·0
7, ...	94,789	121,324	14·5
8, ...	—	156,090	2·0

1 and 4. Natural state.

3, 5 and 8. Oil hardened and tempered.

2, 6 and 7. Oil hardened and annealed.

According to Brustlein, copper steels with more than one per cent. of copper are decidedly red-short; he believes such steels have no future; that copper does not appear to be uniformly distributed through the metal, and that it

* *Bulletin de la Société de l' Industries Minerale*, xiii, 205.

† *Journal of the Iron and Steel Institute*, No. 1, 1889, p. 125. *Journal of the Franklin Institute*, July, 1890, p. 35.

‡ *Journal of the Franklin Institute*, August, 1890, pp. 123, 124.

appears to favor the formation of blowholes.* It has been thought that the red-shortness which usually accompanies the presence of copper is due rather to the formation of sulphide of copper—the copper taking up sulphur from the furnace gases—than to the copper itself.†

W. W. Scranton, of the Scranton Steel Works, habitually makes Bessemer T-rails with 0·51 to 0·66 per cent. copper; he states they are non-redshort.‡

Copper-steel alloys are almost too new to determine for what particular purposes they would be most useful. It is stated in the Schneider patents that they are useful for making ordnance, armor plate, rifle barrels and projectiles and also for girders for building purposes and ship plates.

In view of the remarkable elastic limit of copper steel while maintaining at the same time a very considerable elongation, it would not be surprising if its use became very extensive in the arts. It has the advantage of aluminum, nickel and tungsten steels in being cheaper to manufacture. In many of the steel alloys, the alloying metals have to be added to the steel when they are combined with iron, which iron must necessarily contain some carbon—such an increase of carbon in the alloy is nearly always undesirable. Thus, for instance, if the manganese in manganese steel could be added as metallic manganese and not as ferro-manganese (which must contain carbon), we would probably obtain better results with manganese steel.

The undesirable increase of carbon in this way is avoided in making copper steel, for as we have seen, the copper can be added in the metallic state, or as an ore.

Messrs. Ball and Wingham in making their iron copper alloys took advantage of the reducing action of the carbon sulphur and silicon present in the pig iron.§

"The iron, rich in copper, was produced by melting pig iron, and then adding to the molten metal oxide of copper.

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* Howe's *Metallurgy of Steel*, p. 368.

† *Ibid.*, p. 369.

‡ *Ibid.*, p. 83.

§ *Journal of the Iron and Steel Inst.*, No. 1, 1889, p. 124. *Journal of the Franklin Inst.*, July, 1890, p. 35.

The carbon and silicon acted as the reducing agents for the cupric oxide, and the copper was thus introduced into the iron by a 'reaction,' and not by simple solution. A part of the other impurities in the pig iron was also burnt out in this manner, and a metal (A) was obtained which had the following composition:

METAL A.

	Per Cent.
Copper,	7·550
Carbon,	2·720
Manganese,	·290
Silicon,	·036
Phosphorus,	·130
Sulphur,	·190

"This metal was bright, white in color, crystalline, and very hard, but it did not offer any great resistance to impact. Varying quantities of it were then melted down with the basic Bessemer steel previously mentioned.

"The opportunity afforded by the preparation of the metal A was taken for observing the order in which the carbon, sulphur and silicon originally present in the pig iron were eliminated by the oxygen of the cupric oxide added, the percentage of sulphur in the metal having been largely increased for the purpose of this experiment, which consisted in melting the iron in a graphite crucible, and then making successive additions to it of cupric oxide. After each addition of the oxide, the metal was poured, a sample taken for analysis, and the remainder charged into the crucible again and remelted, a further addition of cupric oxide being then made.

"The following table shows the composition of the pig iron used, as well as that of the samples taken after each successive addition of cupric oxide:

Description.	*Silicon. Per Cent.*	*Carbon. Per Cent.*	*Sulphur. Per Cent.*
Pig iron,	1·02	2·60	1·44
First sample,	0·55	2·32	1·27
Second sample,	0·10	2·02	1·12
Third sample,	0·05	1·77	1·18
Fourth sample,	trace	0·61	1·08
Fifth sample,	trace	0·34	0·85

"It will be observed that whilst the silicon was rapidly

oxidized, the carbon was only appreciably attacked after nearly the whole of the silicon had been eliminated; and, further, that the percentage of sulphur was not greatly affected till most of the carbon had been burnt off. This diminution in the percentage of sulphur may, however, to some extent be accounted for by the dilution of the pig iron by the copper reduced from the cupric oxide."

Manganese Steel.—The effect of small amounts of manganese on the strength and ductility of steel appears to be slight. Beginning, however, with about 2·5 per cent., a further increase of manganese diminishes both the strength and ductility, while conferring remarkable hardness. This effect reaches a maximum when the manganese is about five to six per cent., with a further increase the strength and toughness improves while the hardness somewhat diminishes. The maximum of both strength and toughness is probably reached with about fifteen per cent. manganese, the hardness still remaining so great that the metal can scarcely be machined. As the manganese rises above fifteen per cent. the ductility falls abruptly, while the tensile strength remains nearly constant until the manganese passes twenty per cent., when it in turn falls rapidly. Hadfield states that the best composition is that of fourteen per cent. manganese and not over one per cent. carbon. Such a metal is very fluid, solidifies rapidly and with great contraction, does not form blowholes, but pipes deeply, is forgeable, but welds poorly.*

The effect of this high percentage of manganese is obscured by the accompanying carbon, which rises unavoidably with the manganese. Even when containing as much as 21·67 per cent. manganese and 2·1 per cent. of carbon, manganese steel can be forged.

The chief obstacle to the commercial introduction of manganese steel is its hardness. The machining and tooling of some of the grades of this material is almost impossible by the ordinary methods.

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* R. A. Hadfield, on "Manganese Steel," *Journal of the Iron and Steel Institute*, No. 2, 1888.

Manganese steel is not so liable to contain honey-combs as the ordinary steel, and the addition of silicon to obviate unsoundness, is not necessary. It is very fluid, can be run in thin sections, but cools more rapidly than ordinary steel, with a decidedly greater contraction. Manganese steel, containing from four to six and one-half per cent. manganese, even if it has only 0·37 per cent. of carbon, can be powdered under a hand hammer. This grade is extremely ductile when hot. With eleven per cent. of manganese the metal, after heat treatment, has an elongation of twenty-two per cent., and a tensile strength of 110,000 pounds per square inch, while, with about fourteen per cent. of manganese we have fifty-one per cent. elongation in eight inches, and a tensile strength of 145,000 pounds per square inch.* Both castings and forgings are strengthened and toughened by heating to a yellow, or better, to a white heat, especially if suddenly cooled.

The effect of heat treatment on the tensile strength and ductility of forgings is very marked in the case of steel containing about twelve to fifteen per cent of manganese.† Within these limits, reheating manganese steel forgings to whiteness with slow cooling usually increases the strength and ductility to a marked degree; while if quenched instead of slowly cooled, the increase of strength and ductility is even more marked, the tensile strength being sometimes nearly doubled and the elongation jumping from two to forty-four per cent. in some cases. Indeed, it seems quite necessary to quench manganese steel rapidly in order to give it any considerable value. Fortunately, pieces of moderate size do not crack on quenching; but in attempting to quench large pieces, such as armor plates, in which stresses would naturally be much greater than in small ones, cracks are very apt to develop. Heating and quenching, instead of increasing seems rather to lower the elastic limit, already unfortunately low, and it is possible that it may thus injure rather than benefit the metal for many important purposes.

* Howe's *Metallurgy of Steel*, p. 362.

† *Ibid.*, p. 362.

MANGANESE STEEL, FORGED. *Hadfield.* (*Garrison.*)

Numbers.	Composition.					In the "Natural State."			Air-toughened.		Oil-toughened.		Water-toughened.		
	C.	Si.	Mn.	P.	S.	Tensile Strength. Pounds per Sq. Inch.	Elongation. Per Cent. in 8 Inches.	Contraction of Area. Per Cent.	Tensile Strength. Pounds per Sq. Inch.	Elongation. Per Cent. in 8 Inches.	Tensile Strength. Pounds per Sq. Inch.	Elongation. Per Cent. in 8 Inches.	Tensile Strength. Pounds per Sq. Inch.	Elongation. Per Cent. in 8 Inches.	Contraction of Area. Per Cent.
1,	·20	·03	·83	·09±	·06±	73,920	31	46	—	—	—	—	—	—	—
2,	·40	·15	2·30	·09±	·06±	125,440	6	7	—	—	—	—	—	—	—
3,	·40	·09	3·89	·09±	·06±	85,120	1	—	—	—	—	—	—	—	—
4,	·52	·37	6·95	·09±	·06±	56,000	2	—	—	—	—	—	—	—	—
5,	·47	·44	7·22	·09±	·06±	60,480	2	—	47,040	2	42,560	2	—	—	—
6,	—	—	7·50	·09±	·06±	87,360	4	—	60,480	5	56,000	3	51,520	2	—
7,	·50	·28	7·90	·09±	·06±	—	—	9	—	—	—	—	56,000	2	—
8,	1·00	·42	9·15	·09±	·06±	—	—	—	62,720	8	67,200	7	—	—	—
9,	—	—	9·20	·09±	·06±	89,600	6	10	—	—	94,080	17	—	—	—
10,	·61	·30	9·37	·09±	·06±	73,920	5	—	—	—	—	—	—	—	—
11,	·95	·21	10·11	·09±	·06±	85,120	5	—	85,120	16	85,120	15	—	—	—
12,	·85	·28	10·60	·09±	·06±	76,160	4	—	87,360	14	91,840	20	87,360	15	—
13,	—	—	—	—	—	—	—	—	91,840	17	94,080	19	—	—	—
14,	·72	·37	10·83	·09±	·06±	—	—	—	—	—	—	—	89,600	17	—
15,	—	—	—	—	—	—	—	—	—	—	—	—	103,040 (*a*)	22 (*a*)	—
16,	—	—	—	—	—	—	—	—	—	—	—	—	112,000 (*a*)	25 (*a*)	—
17,	—	—	—	—	—	—	—	—	—	—	—	—	118,720 (*a*)	29 (*a*)	—
18,	—	—	—	—	—	87,360	4	8	—	—	—	—	—	—	—
19,	·85	·37	12·29	·09±	·06±	—	—	—	—	—	—	—	141,120	45	—
20,	—	—	—	—	—	—	—	—	—	—	—	—	143,360	45	—
21,	1·10	·16	12·60	·09±	·06±	87,360	2	—	—	—	—	—	145,600	50	—
22,	—	—	12·70	·09±	·05±	105,280	6	—	82,880	11	112,000	28	120,960	27	—
23,	·92	·42	12·81	·09±	·06±	87,360	5	—	—	—	—	—	—	—	—
24,	—	—	—	—	—	—	—	—	107,520	20	129,920	32	136,640	37	—
25,	·85	·23	13·75	·09±	·06±	—	—	—	—	—	—	—	143,360	45	—
26,	—	—	—	—	—	—	—	—	—	—	—	—	143,360	45	—
27,	—	—	—	—	—	—	—	—	—	—	—	—	147,840	49	—
28,	·85	·23	13·75	·09±	·06±	—	—	—	—	—	—	—	136,640	48	—
29,	—	—	—	—	—	—	—	—	—	—	—	—	143,360	50	—
30,	·85	·28	14·01	·09±	·06±	—	—	—	—	—	—	—	145,600	51	—
31,	1·15	·84	14·27	·09±	·06±	80,640	2	—	—	—	—	—	150,080	44 (*b*)	—
32,	1·15	·84	14·27	·09±	·06±	—	—	—	107,520	14	123,200	27	154,560	46	—
33,	1·10	·32	14·48	·09±	·06±	—	—	—	—	—	—	—	156,800	40	37
34,	1·24	·16	15·06	·09±	·06±	87,360	1	—	—	—	—	—	141,120	37	—
35,	1·54	·16	18·40	·09±	·06±	109,760	2	—	109,760	5	—	—	136,640	31	—
36,	1·83	·26	18·55	·09±	·06±	114,240	1	—	105,280	2	—	—	118,720	10	—
37,	1·60	·26	19·10	·09±	·06±	96,320	1	—	87,360	1	—	—	123,200	5	—
38,	1·90	·32	19·98	·09±	·06±	116,480	1	—	—	—	—	—	132,160	4	—
	2·10	·46	21·69	·09±	·06±	80,640	9	—	91,840	1	51,520	0	—	—	—
									76,160	12	73,920	11	—	—	—

"Natural state" means that the metal was simply cooled slowly after forging ceased.
"Air-toughened" means that, after cooling, it was reheated to a yellow heat and allowed to cool slowly in the air.
"Oil-toughened" and "water-toughened" mean that, after forging, it cooled slowly, was then heated to a yellow heat, and quenched in cold oil or water.
The fractures of bars with from three to nine per cent. of manganese were always coarse and granular; those of bars with more than nine per cent. of manganese which had been water-toughened were silky and fibrous.
The contraction of area of the water-toughened pieces is usually from thirty to forty per cent.
(*a*) Lowest, highest and average results of twelve tests.
(*b*) This piece is still unbroken. Hadfield, *Journ. Iron and Steel Inst.*, 1888, II.; *excerpt Proc. Inst. Civ. Eng.*, XCIII, 1888, p. 40, *et seq.*

In the cast state, manganese steel is extremely brittle and hard. When forged, a remarkable increase in strength takes place, the tensile strength averaging about twenty-five tons, with three per cent. elongation.

Howe states,* "under stress, manganese steel acts very differently from wrought iron and carbon steel. With 125,000 pounds (fifty-six tons) tensile strength it may begin taking serious permanent set under stress of 35,000 pounds per square inch, so in this respect it is little better than common soft steel with (say) 60,000 pounds tensile strength.

[*To be continued.*]

CONFLAGRATIONS IN CITIES.

By C. J. H. Woodbury,

Vice-President Boston Manufacturers' Mutual Fire Insurance Company, Boston, Mass.

[*A lecture delivered before the Franklin Institute, Philadelphia, Jan. 23, 1891.*]

The lecturer was introduced by the Secretary of the Institute, and spoke as follows:

Members of the Institute, Ladies and Gentlemen:

Cities have always been an expression of civilization, measured by the skill and enterprise of their builders. Every human resource, stimulated by sentiment for home, avarice for possessions, and desire to be equal to posterity, has contributed means for fashioning them with a view to the utmost permanence; yet their history has been a continuous record of conflagrations whose devastating lines form historical divisions, separating the old from the new, and making swaths which have often proved to be paths for new improvements, but achieved at oppressive costs which would never have been entered upon voluntarily by the owners of the property destroyed. Most of these fires have resulted in forcing reforms in regard to streets, buildings,

* *Metallurgy of Steel*, p. 363.

laws and health. Blessings they may have been, but to those directly interested at the time, most completely disguised.

The accounts of early fires ascribe them to the visitation of an angry Jehovah or Jupiter, by the exercise of a supernatural power, and it is indeed without question that many of these instances of destruction were the result of natural causes, as earthquakes, volcanic eruptions and lightning.

However, little is to be feared from the latter form of visitation by any possibly reprobate city of to-day; thanks to the inductive effect, as well as the direct diffusion of the lightning by the much-abused overhead wires, which serve as a guardian between the earth and the sky, robbing the thunderbolt of most of its former dangers.

The Christian Era is only midway back to the earliest account of the burning of a city, contained in the Holy Writ [Gen. xix.], describing the rain of fire and brimstone on Sodom and Gomorrah. So terrible was this devastation that the once fertile sites of these cities are to this day a sterile waste.

It is evident from the record of laws fixing penalties for such crimes, that human agency was well recognized as a criminal cause of fires among the ancients. Among the Egyptians arson was punishable with death, and the Mosaic law, enacting a similar penalty, was probably a repetition of the same. In China it is forty blows for an accidental fire, and 100 blows for a malicious fire in one's own house, and for causing a fire in any other house, death.

Notwithstanding these severe penalties and the absence of insurance policies, the cities of the Orient, largely built of bamboo covered with thatch, and having narrow lanes, though well fitted to withstand earthquakes, are continually subject to conflagrations. One who was a resident in China for many years has stated, as a matter of opinion, that he considered the average existence of dwellings in cities to be about five years.

In Japan, so-called fire engines, consisting of square, wooden pumps attached to tubs, are hung from verandah roofs. [Morse, *Japanese Homes*, p. 65.] These devices are of

insufficient capacity and generally out of repair, like much of the independent fire apparatus among Occidental nations, and the main reliance is upon mud or stone buildings in the yard at the rear of the houses. These serve as safes in which the household goods can be stored in face of threatened conflagration. Such buildings are called by the Japanese, "kura," and by foreigners, "go-downs," although the latter term is also applied to store-houses owned by Europeans.

Oriental cities have been devastated by fire again and again. The courses of such conflagrations have been plotted on maps of Japanese cities by Dr. T. C. Mendenhall, Superintendent of the United States Coast Survey, formerly of the University of Tokio, and later of the United States Weather Bureau, and it has been found that the general trend of these fires is coincident with the direction of the prevalent winds.

Historical Fires.—Among the great fires of history, undoubtedly the burning of the Serapæum Library, at Alexandria, in the year 640, by the Caliph Omar I, is most widely mourned, as the destruction of 500,000 volumes cut off much of the record of human knowledge at that time. The general impression of the importance and significance of this fire is, no doubt, augmented in great measure by the barbaric answer of this Saracen conqueror, who replied to the protest against the burning with: "If the books are against the Koran, they are pernicious and must be destroyed. If they agree with the Koran, they are redundant and need not be preserved;" and it is not generally remembered that Julius Cæsar burned a larger library of 700,000 volumes at Alexandria, known as the Brucian Library, B.C. 48, nearly 700 years before the burning of the Serapæum Library by Omar I.

At times of sack and pillage, Jerusalem has been burned time and again; the most noted instance being at the siege by the Romans under Titus, during the year 70, when a faction called the Sicarii set the city on fire in many places, and eventually 1,100,000 of the inhabitants perished by fire and the sword.

Constantinople has, like all Oriental cities, suffered severely from fires, a large part of such losses being undoubtedly due to the fatalism of the Mohammedans, who bow to their kismet. Said a Sultan: "If it be the will of Allah that my favorite city burn, it is the will of Allah."

In Dillaway's quaint account of travels in the Levant in 1737, it is stated that the Sultan is summoned three times to a fire in Constantinople, and if the fire lasts an hour he is obliged to attend in person, and bring mules laden with piastres for the firemen. The proverbial liberty during fires exists on these occasions, for custom gives to the women the privilege of execrating the Sultan with impunity whenever he appears at a fire.

But it is evident that this custom of receiving piastres and bestowing virulence has in nowise tended to diminish the fires any more than the system of giving a reward to the company first at a fire under the volunteer departments of the last generation effected such results.

Rome continues to be the eternal city in spite of numerous fires, whose reported number may be greater than that of any other historical city, merely because the records are more perfect. Many of these fires are of great interest at the present day, because the lessons which they taught were well learned, and gave rise to new and original methods in preventing the repetition of the same incidents.

A great fire at Rome 12 B.C., caused the Emperor Augustus to take measures for increasing the defence against fire, which had been hitherto in the hands of bodies of police, numbering twenty or thirty, stationed in various portions of the city, and reinforced at times of fire by companies of volunteers. He appointed new officers with the rank of magistrates, who were entitled to wear magisterial robes. Each was attended by two lictors, and provided with a fire organization of 600 slaves.

It is probable that this was not entirely satisfactory in its operation, because six years later another fire caused him to undertake further reforms on a scale fully characteristic of him who "found the city built of brick, and left it with palaces of marble." He increased the fire department

to a scale commensurate with the needs of the city. Seven thousand freemen were organized into seven battalions, and one battalion was quartered in every alternate ward of the city. These men made careful inspections of the kitchens, of the heating apparatus, and of the water supply in the houses; and every fire was the subject of judicial examination. The cost of the organization was maintained by a tax of twenty-five per cent. on the sale of slaves. [See *Ancient Rome*, Lanciani, pp. 221-230.]

It is undoubtedly true that this organization, to which only a brief reference has been given, was of the greatest efficiency, for I can find no reference to any great fire in the city for seventy years, when it was set on fire by the Emperor Nero in the year 64. The account of this fire, given by Lanciani, as the result of the latest investigations, is so different from the generally accepted tale of the city being set on fire by the malice of Nero, "who played the fiddle while Rome burned," that the recent version may be of interest.

Nero desired to make many changes in the streets of Rome by increasing their width and making many of them more direct, and also to introduce many improvements by reconstructing public buildings. His efforts in this direc- were met by an opposition from property-owners, and were also embarrassed by the fact that the city abounded in temples, altars and shrines which were inviolate.

The Emperor directed two architects, Severus and Celer, to prepare plans for a re-arrangement of the streets in certain parts of the city, making them as near to straight lines and right angles as the hilly configuration would render feasible. Numerous public squares were laid out and a system of sewers planned.

Regulations for buildings were prepared, in which it was provided that the height of houses should not exceed double the width of the street, that each house should be completely cut off from the adjoining buildings, that each house should have a portico in front, and that wood ceilings should be excluded from the first stories of buildings.

Tents and booths were secretly prepared, and vessels were

sent to various Mediterranean ports after grain with orders to rendezvous at the delta of the Tiber on a certain date. In accordance with his plan the city was fired in numerous places, and of the fourteen wards, three were entirely destroyed and seven burned in great part.

The crowds driven out of their homes found the booths in the outskirts of the city ready for them. The grain-laden vessels appeared in time, and the towns-people were fed and housed during the rebuilding; the whole plan having been carried into effect without exposure, famine, or loss of life, although the population numbered at the time 2,000,000.

Improved hygienic conditions have been the usual result of conflagrations, because in the natural course of events those engaged in rebuilding have availed themselves of opportunities to introduce improvements, and often the causes leading to certain local epidemics have been destroyed; but it is without parallel that a city should be burned from hygienic motives.

Two notable examples of contagions stopped by conflagrations are the burning of Moscow by the besieging Tartars, in July, 1570, when the plague was stopped, and secondly the fire in London, September 2, 1666, which also stopped the plague, and it has been unknown there since.

This London fire is properly called the Great Fire of modern history, because the reforms which were started in consequence of it are living issues in the municipal affairs of to-day. The fire was caused by an overheated baker's oven; and in the course of four days it swept over 463 acres, burning 13,200 houses, eighty-nine churches, and St. Paul's Cathedral, causing a damage estimated to be £10,716,000, say $53,500,000.

The number of contemporaneous books upon the subject of this fire is between 200 and 300, but the greater part of them, judging from the list of their titles, contains but little information. The wonderful diaries of Samuel Pepys and Sir John Evelyn contain about all that is known in regard to this fire. Pepys was a man of the world, among the official set as Secretary of the Admiralty, a keen

observer, and perhaps a journalist born out of due time. Evelyn was one of the gentry, complacent, more than pious, and quite philosophical in the bent of his mind. The one was the most perfect foil for the other.

Under the direction of Pepys the fire was stopped by blowing up buildings, which was, at the time, the only method of reducing a fire that had grown beyond the capacity of the small fire engines. These were on large tubs, and threw a stream of water directly on to the fire, as hose was not invented until ten years later (1672) by Van der Heide.

Important results followed the action taken in consequence of the great fire. The building regulations enacted provided for the reconstruction of the city with wider streets and better water supply and sewers—thus fitting London for the position of great commercial supremacy which that city has since maintained. The principle of modern fire insurance was also put into practice shortly after the fire and as a consequence of it.

At a far earlier date there had been a form of marine insurance, and also a method of mutually indemnifying against fire, water and robbers, by the guilds, but both of these were by a mutual compact, socialistic in its nature, and not comparable to underwriting in modern practice, with its general commercial applications.

All cities have gained much from the experience derived from conflagrations. The French building laws are said to have been improved in great measure from action taken as a result of a fire in Paris, in 1716, although the *Code Napoleon* (1804) increased these rules and restrictions to an extent praiseworthy in its results, of which the best statement in English is probably in the paper by W. L. Boswell, "Fire Defences of Paris." [*Journal Franklin Institute*, February, 1890.]

The firing of cities has been used as a desperate means of defence, which injured friends and foes alike: one notable instance being the burning of Jerusalem by the Sicarii, to which reference has already been made.

Another example of burning a city in self-defence is the

burning of Moscow, September, 1812. Napoleon, in his campaign against Russia, in revenge for his repulse as a suitor for the successor of the yet undivorced Josephine, entered Moscow, September 14th, proposing to make winter quarters there. On that very day fires began to appear, and in less than a week the city was in ashes. The loss of life is said to have been 20,000 of the sick and wounded, with a direct loss to the French of 40,000. The invaders were thus driven back in that terrible retreat in the dead of winter.

The cities of America, on account of the larger amount of wood in their construction and the prevalence of irresponsible methods of building, have suffered severely from fires, and it is from these fires that conclusions are to be drawn for suggesting measures that will tend to diminish their recurrence.

Some of the possible elements of hazard, like those due to electricity or to very high buildings, are too new for their exact weight to be formulated; and others, like the attempt of the Indians to burn New York in 1711, have ceased to exist, at least in the older portions of the country. But such hazards have always existed at the frontier in the westward growth of civilization, and the daily papers contained an account of the burning of the town of Pocatello, Idaho, by the Indians on the eighth of this month. I do not, however, care to discuss the insurance liability from this hazard.

The first devastating fire in America was probably the one occuring at Boston, March 20, 1760, when 400 dwellings and stores were burned, causing a loss of £100,000. Generous contributions were sent from other cities to the people of Boston; and in 1811, when a large portion of the city of Newburyport was burned, the citizens of Boston, with a liberality which they have never failed to tender to other cities that have suffered by fire, took the initiative in subscribing for the relief of the sufferers.

In the Colony of Massachusetts Bay, regulations in regard to construction of chimneys and thatched roofs were made as early as March 16, 1630, and various enactments were made at later dates. The ordinance at the town-meeting at Boston, March 14, 1645, made provision that each house-

holder should have ladders long enough to reach the ridge of his house, and a pole "about twelve feet long, with a good large swab at the end of it;" and various graded penalties were provided for those not conforming to the law. [*History Boston Fire Department*, Brayley, p. 7.]

It is difficult to obtain a record of early American conflagrations outside of local histories. New Orleans was burned in 1777, and every city seems to have had more or less of similar calamities.

Philadelphia has been remarkably free from conflagrations in comparison with other large cities. This may be in part ascribed to the early introduction of water, giving that city for several years an advantage in the way of an abundant supply of water. In a greater measure it is due to the abundance of land, making it feasible to avoid the density of buildings which is common to most cities; and in chief measure it is probably due to the prevalent and wise custom of people owning their homes, a fashion which in many other respects tends to prosperity and good order.

Reference has been made to numerous fires on account of their relation to the growth of various methods of protection; but in Philadelphia it appears that the excellent record is due to the initiative measures, beginning with the act of the Provincial Legislature, in 1696, directing that every householder should keep at his dwelling a bucket ready for use, and a swab twelve or fourteen feet long, under penalty of twelve shillings for neglect, and forbidding the burning out of foul chimneys, penalty forty shillings, and the smoking of tobacco on the streets day or night, the fine for the latter being ten pence.

The first insurance written with American capital was probably marine insurance, written at Philadelphia, in 1721; although marine insurance on vessels owned at Philadeldelphia was written in London shortly after 1683. [See *History of Insurance in Philadelphia*, by J. A. Fowler.]

New York was visited by a severe conflagration in the southern part of the city, on December 16, 1835, which extended over an area of forty acres, destroying 674 houses and causing a loss which has been estimated as high as

$30,000,000, on which there was only $8,000,000 insurance, an amount which ruined several insurance companies. It has been held by some that the destruction of property by great fires has rendered them the cause of financial depressions; and in this connection it has been stated that this New York fire was the cause of the panic of 1836.

Philadelphia does not appear to have been visited by a great fire until July 9, 1850, when a fire along the Delaware River front, at Vine Street, extended over eighteen acres, causing a loss of life estimated as high as thirty-three, in addition to 120 wounded, and a pecuniary loss of $1,500,000.

The memory of this fire is perpetuated in the slang of to-day. An explosion was caused by a coincidence in the contents of a warehouse which contained sugar in the upper stories and saltpetre below. When the saltpetre came in contact with the sugar a violent explosion ensued, and for a while spread the fire beyond all efforts to control it. This catastrophe and the controversies which followed it gave rise to the satirical question: "Will saltpetre explode?" and was followed by an ordinance forbidding its storage in quantity in the city or on vessels in the river. This act was afterwards modified (April 14, 1851).

A greater fire occurred August 4, 1869, when, by the burning of Patterson's bonded warehouse, at Lombard and Front Streets, 24,000 barrels of whiskey were burned, gutted or stolen, causing a loss of about $2,000,000. If other large fires have conduced to order and wiser laws, the direct result of this fire led to disorder, for the opportunity of drinking without stint or price proved too great a temptation for many, and the temperance cause languished to an extent without precedent.

One of the first of the more recent conflagrations was the burning of Portland, Me., July 4, 1866. The fire was caused by a boy throwing a fire-cracker into a cooper's shop, for the avowed purpose of scaring the workmen. In this respect the act was an unparalleled success, the damage being about $10,000,000.

The eloquent letter of John Adams, July 3, 1776, after the resolution preceding the Declaration of Independence

had been passed, in which he said of the Fourth of July: "It ought to be solemnized with pomps, shows, games, sports, guns, bells, bonfires and illuminations from one end of the continent to the other, from this time forward forever" [*Letters of John Adams to his Wife*, p. 128], has many catastrophies to answer for.

The Chicago fire, October 9, 1871, was one of the largest in all history, devastating an area of three and one-half square miles, and causing a loss of about $190,000,000, on which insurance was paid to the amount of about $100,000,000. Two hundred and fifty lives were reported lost in this fire.

Thirteen months later, to a day, Boston was visited by a fire which extended over an area of sixty-five acres, burning the best mercantile buildings in the city, and causing a damage of $75,000,000, on which there was insurance to over $65,000,000.

Inspection.—As in other instances, these casualties gave rise to many plans for better building laws, and for the reorganization of fire departments. In the course of such changes many acts of injustice have been perpetrated by those who did not grasp the whole force of the chain of circumstances causing these devastating fires, conditions too strong to be controlled by any one set of rules formulated at white heat after a conflagration.

These cities had great fires, and will, in the nature of things, have other great fires. Conditions exist which, in the event of fires starting in certain localities and of any error in promptly giving the fire alarm, cannot fail to produce disastrous results.

The causes of fire are as infinite as the varying conditions of the numberless possessions of mankind; and beyond that the forces of nature contribute in no small degree to the fire loss.

Whether it be the overheated baker's oven at London, the balky cow at Chicago, the neglected waste in the engine room at Boston, all great fires result from neglected small ones.

Every method of construction, every process of manu-

facture, every material in commerce, as well as every type of fire apparatus, and the orderly conduct of affairs bears some relation to the fire hazard. The function of the underwriter is not merely to give to these elements their just weight, but yet more to rise from a consideration of physical conditions to the higher and ethical questions relating to the moral hazard as measured by the probity of owners, who are always possessed of every opportunity to effect the destruction of their property by fire. The facility with which insurance can be effected, and the readiness with which losses are paid, renders incendiarism the great undetected crime of the present day.

It requires no argument to prove that the most efficient means of diminishing the amount of loss by fire is to lessen the number of causes of fire; but the best method of carrying such measures into effect is a question upon which there are legitimate differences.

Inspections by men employed by associations of underwriters have given the most satisfactory results, but it may justly be queried whether this is the proper source for such an espionage over the community. These inspectors are employed by associations composed of competitors in the insurance business, and they are without any legal authority to enforce obedience to suggestions which are admittedly for the weal of all.

Their requests are, for the most part, complied with; but the results are a benefit to the community, and it would appear that this service should be performed by persons clothed with authority from a municipality, as a part of the protective system which now extends protection to person and property by means of the police, the water supply, and the fire departments, leaving to the underwriters their legitimate work of insuring property at prices based upon the estimated hazard. If the risk of destruction by fire is reduced, it will be a benefit to the community, which will be gladly recognized by underwriters in the diminution of premiums based on the new condition of affairs.

The methods of fire patrol carried on by members of the fire departments in many cities do not comply with the

offered suggestions. There should be a patrol by members of the fire department, who should systematically inspect every building, searching into every preventable cause of fire, with authority to cause the proper remedies to be carried into effect. The building laws refer almost solely to the new buildings erected within a few years, but a commission like this would be able to introduce inexpensive modifications into old buildings, which would greatly modify many dangerous conditions of hazard.

[*To be continued.*]

PROF. LIPPMANN'S HELIOCHROMY.

By F. E. Ives.

[*A communication to the Chemical Section, April 21, 1891.*]

At the March meeting of this section, I made some comments upon the alleged solution of the problem of photography in natural colors by Prof. Lippmann, of Paris, expressing some doubt as to the possibility of obtaining such alternate zones of "light and darkness" in proximity to the mercury mirror as are called for by Prof. Lippmann's theory, and also as to the possibility of reproducing the compound colors by means of interference laminæ. I afterwards communicated my doubt to Prof. Himes, of Dickinson College, and asked for an expression of his opinion. He kindly wrote me a long letter, from which I quote as follows:

"As far as I have been able to follow Prof. Lippmann, I am more hopeful than you perhaps are in the direction of compound colors, and more nearly satisfied with the theoretical explanation, although, of course, at this early stage it must be regarded, of course, only as provisional, and there are many questions that both of us would like to ask, some of which Prof. Lippmann might possibly be able to answer by this time and others I am just as certain he could not. I will just note hastily the points upon which I have less difficulty and doubt than you seem to have, premising first

that you concede the fact that Prof. Lippmann has succeeded in getting a photographic impression of the spectrum in which can be recognized at least the colors in their order—some say brilliant and perfect—but I think Prof. Lippmann's account is more moderate and modest. But this is not the greatest feature of Prof. Lippmann's publication. This has been done long ago and by many, and possibly better than he has accomplished it, but he has succeeded in *fixing* it, and that by the ordinary photographic method, and his whole process, withal, is so simple and complete that it invites and encourages experiment with it, which I have great hope will lead to practical results.

"As to his theory we may think what we please. With me it has this in its favor, that the appearance of all previously obtained heliochromic results by Becquerell and others, whether flowing from systematic investigation or from accident, as in many cases, conforms to that of Prof. Lippmann's results, and can best be described as that of *interference* colors. There are even those who intimate that after all Prof. Lippmann adopted a theory and line of investigation already outlined.

"I have no difficulty in regard to the interference of direct and reflected waves so as to produce so-called stationary waves of definite length and frequency. The ocular demonstration of such waves, usually employed in lectures, by means of a stretched spiral cord or gum tube, attached at one end to a hook, and held at the other end by the hand, on which regularly timed impulses by the hand produce interfering direct and reflected waves, is very satisfactory at this point. The completed analogue in case of sound is to me conclusive of the plausibility of the theory of Prof. Lippmann. Savort, in the early part of the century and more recently Lord Rayleigh (in 1888) by a series of classical experiments demonstrated the presence of stationary sound waves, with their spaces of sound and silence by the interference of direct waves with those reflected from a board using a sensitive flame to explore the space. A double reflecting surface may be necessary to present interference colors to the eye as you state, as the rays should both be

moving toward the eye, but to produce the stationary luminous undulations, or zones of maximum movement or maximum energy and zones of rest or of minimum movement; of the ether particles, the interference of an incident and reflected ray from one surface will be sufficient condition. These are hardly to be called zones of light and darkness. A ray of light is invisible as such; it produces visible effects, so here the zones of differing energy in the ether particles produce varying effects upon the film in which they are formed, effects which we recognize as photographic.

"These effects are not the production of pigment colors, as up to this time seems to have been the expectation in heliochromy, but they are rather in nature of change of structure, laminated deposits of silver, so to say.

"As to the rendering of compound colors, I have not seen much claimed as accomplished in this direction. There is a well-grounded hope, I believe, but the rendering of the spectrum and the perfect fixing of it are the chief claims of Prof. Lippmann, as I understand it. I would not draw, or allow the theory to draw, the line of the impossible too near to the present achievement to prevent investigation and experiment with compound colors. The whole doctrine of perception of compound colors would not permit us to deny such possibility. Prof. Lippmann has certainly started scientific thought and investigation, as far as heliochromy is concerned, in a new direction, by results that commend our admiration and a theory that is not only possible, but a most excellent working hypothesis."

Capt. Abney, who recently visited Prof. Lippmann, also appears to endorse his theories, but does not regard his process as a step in the direction of practical photography in colors. The following report of Capt. Abney's remarks upon this subject, at the recent Camera Club Conference, is from the London *Photographic News*, of April 10th:

"Photography in natural colors was the next question to which the President turned his hearers' attention. The 'accomplished fact,' as some of the newspapers led their readers to suppose, is as old as photography, for the discovery of photography in colors has been made, according

to some people, over and over again. Being in Paris a week ago he had the opportunity of visiting M. Lippmann. He found that gentleman to be a true man of science, with all the modesty of a real investigator. The color plates about which we have heard so much are due to interference, and not to pigments, and their effect varies according to the angle at which the plate on which they appear is held. Capt. Abney then proceeded to describe how these colors are obtained, by use of a mercury trough, as already detailed in our pages. He pointed out that, to obtain the colors, exposure to a bright spectrum was necessary, and that development must be brought about by alkaline carbonates, and the image intensified with silver. Both exposure and development must be exactly correct, or no colors are apparent, and the best results are gained with dry plates prepared with albumen and collodion. He looks upon the results of M. Lippmann's experiments merely as a verification of Newton's law, and not as a discovery of photography in color. M. Lippmann has certainly succeeded in fixing interference colors, but the process is clearly one of extreme difficulty. It is a misfortune both for M. Lippmann and his predecessor, Dr. Koch, that their experiments should have been dealt with by the ordinary reporters, because these reports have led the general public to expect far more than the experiments in either case justified."

COMPOSITION OF BOILER SCALE AND THE COMPOSITION OF THE FEED WATER FROM GALVESTON, TEX.

By George A. Koenig.

[*Read at the stated meeting of the Chemical Section, held June 16, 1891.*]

The city of Galveston is built upon a narrow tongue of land which separates the Gulf of Mexico from Galveston Bay. I am informed that the surface of this land consists of a conglomerate or natural concrete, some twelve to eighteen inches thick. Over this extends sand three to four feet thick, and under the concrete a bed of quicksand of very great depth; its depth being practically unknown. The conglomerate offers very good foundation for all buildings. To obtain feed water for steam boilers, several of the industrial establishments have driven tube wells into the quicksand to great depth. The well of the Galveston Rope and Twine Company, whose water is the subject of this paper, is said to be 1,500 feet deep. It is probable that the sinking was continued until the flow of the quicksand stopped.

The water from this well is perfectly clear, and no sediment was found in the vessel. It has a very salty taste, and contains, in 1,000,000 parts:

SiO_2,	=	29·9
Fe_2O_3,	=	3·5
Al_2O_3,	=	1·5
CaO,	=	132·8
$MgCl_2$,	=	197·6 (MgO = 83·2)
$NaCl$,	=	5489·3
SO_3,	=	1·99

CO_2 was not determined; but from the composition of the scale it must be inferred that there is probably a little more CO_2 present in the water than is required to hold the calcium in solution as hydro-carbonate. Since the percentage of sodium chloride is 0·55, and since the sea washes, so to speak, the very locality, the conclusion might easily be reached that this artesian water is simply filtered

sea water. This view is surely entertained at the locality, and is also held by some chemists. There are several reasons why this view must be abandoned. The supply of these artesian wells has nothing in common with sea water. An analysis of the water taken in the surf of Atlantic City this spring gave me, in 1,000,000 parts:

$(SiO_2 + Al_2O_3 + Fe_2O_3)$, ...	= 6·0
SO_3, ...	= 1965·0
NaCl, ...	= 23320·0

Sea water, then, contains about one-fifth as much of silica, ferric and aluminum oxides; it contains 1,000 times more of SO_3 and over four times as much of NaCl. What could have become of the sulphates if this artesian water were filtered sea water? It is simply inconceivable to suppose that the filtering through fine quartz sand would remove the sulphates, which are very soluble. We might understand that the flowing through the quartz would increase the silica in the water, but again we could not account for the loss of three-fourths of sodium chloride. Thus we are brought to the only possible explanation, namely, the existence of a deposit of rock salt under the quicksand. We know that there is such a deposit at the mouth of the Mississippi River, of probable Miocene age, and which has been exploited for many years. We know that whenever a salt bed forms from evaporation out of sea water the sulphates crystallize out first; the salt always overlies either anhydrite or gypsum, even the kieserite ($MgSO_4 + H_2O$) is found at Stassfurt, in the lower levels. The top beds always contain the easily soluble chlorides of magnesium and calcium and potassium, as at Stassfurt, but not necessarily everywhere. I tested five grams of the salt obtained by evaporation of the Galveston water for potassium, but found much less than there is in the sea water at Atlantic City. This is surely another anomaly, but notwithstanding, I think the evidence is strongly in favor of assuming the top strata of a salt bed as the source of the Galveston artesian water. The Galveston Rope and Twine Company having observed that the boiler-plates of a neighboring establishment had been very rapidly destroyed by the forming of

pin holes, resolved to have the matter investigated before their new boilers (from the Edgemoor Iron Company) had suffered a similar fate, and sent samples of their feed water as well as of their scale. After investigation, the writer proposed the use of soda ash as a preventive. But some other parties having recommended tri-sodium phosphate, a new sample of the scale was submitted some four weeks later. The analyses of both samples (*A*) before and (*B*) after the use of the tri-sodium phosphate are here given:

	A.	*B.*
SiO_2,	= 11·86	18·76
Fe_2O_3,	= 2·80	2·40
Al_2O_3,	= 0·30	0·66
P_2O_5,	= 0·10	0·58
CaO,	= 9·20	7·64
MgO,	= 43·74	40·28
CO_2,	= 8·86	9·72
H_2O,	= 23·14	19·96

The scale is thin and gray in color. It disintegrates easily. Under a power of 500 diameters it is resolved into an aggregate of single crystals, some prismatic, some tabular. The latter show a hexagonal combination of the basal plane with a positive and negative rhombohedron and resemble the mineral brucite (MgH_2O_2). The prismatic crystals are six-sided with the basal plane. However, they appear to be orthorhombic from their behavior in polarized light.

The substance gelatinizes with hydrochloric acid. There must be consequently a silicate present. The variation in the percentage of silica (this has been called sand, erroneously) is striking. It would be very interesting if the nature of the silicate could be ascertained. It might by chrysolite, which gelatinizes with hydrochloric acids. Assuming this to be the case, and it seems probable because the form is orthorhombic, analysis *A* would assume the following mineralogical interpretation:

Chrysolite (Mg_2SiO_4),	= 27·67
Aragonite ($CaCO_3$),	= 16·4
Hydromagnesite ($CO_3Mg_2H_2O_2$),	5·0
Brucite, (MgH_2O_2),	37·0
Götheite ($FeH)O_2$,	3·2
Hygroscopic water, etc.,	11·0

It is clear that the destruction of the boiler iron is caused by the formation of magnesium hydrate from the chloride, according to the equation

$$MgCl_2 + 2H_2O = MgH_2O_2 + 2HCl$$

If a sufficient quantity of Na_2CO_3 be added to the water, there is no precipitate formed at ordinary temperature; but at 80° C. a flocculent deposit follows of magnesium or calcium carbonates.

Analysis *B* shows that the tri-sodium phosphate had very slight effect. It would not be well to reject it on this account, because it may not have been introduced properly. But it seems to me that the carbonate should be recommended in such cases. The latter is on trial at Galveston now, and after some time another sample of the scale will be submitted.

EWING'S THEORY OF INDUCED MAGNETISM.

By Prof. Henry Crew.

[*Read at the meeting of the Electrical Section, held May 5, 1891.*]

The labors of Rowland, Stoletow, Wiedemann and Ewing have brought to light so large a number of magnetic phenomena that any general principle on which they may be explained would receive a warm welcome at the hands of all interested in this rapidly growing subject.

Any generalization of this kind would be called upon to explain the following phenomena, which are selected each as typical of a large *class* of well-known facts.

(I) *The behavior of a piece of iron when placed in a magnetic field whose strength is made to pass through a cycle of changes.*

(*a*) For magnetizing forces ranging from $\frac{1}{50000}$ to $\frac{1}{25}$ of a C. G. S. unit, the intensity of magnetization is proportional to the magnetizing force (Rayleigh, *Phil. Mag.*, March, 1887).

(*b*) For a range of magnetic forces extending (roughly) from $\frac{1}{25}$ to 5 C. G. S. units the magnetization increases with a rapidity enormously greater than the strength of field.

(*c*) From this point on, as the force continues to increase

the permeability decreases and the induction approaches a limit which, the work of Ewing and Low (*Phil. Trans.*, 1889), leads us to think, has for a value about 40,000.

(*d*) If now the magnetizing force be diminished, the magnetization diminishes, ***but not so rapidly***, until, when all the force is withdrawn, there still remains a perfectly definite magnetization, which is used as a measure of the "retentiveness" of the iron under the conditions of the experiment.

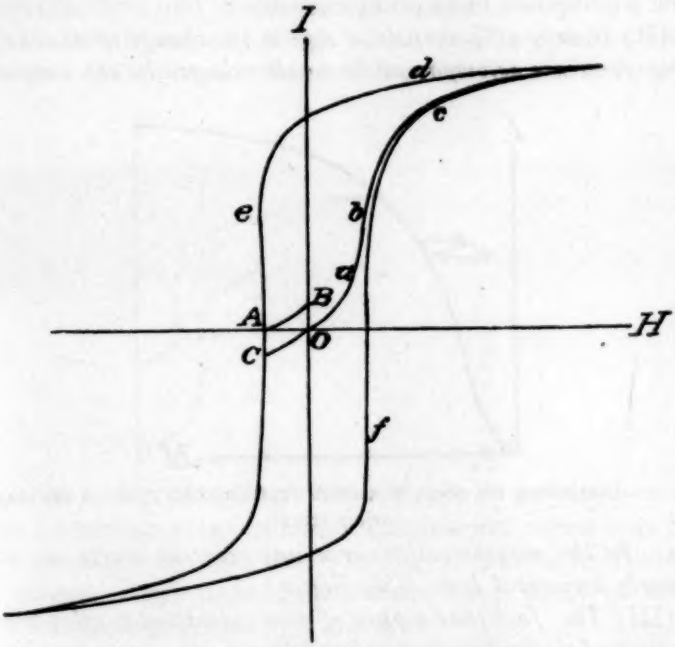

FIG. 1.

(*e*) If next the magnetizing force be reversed the magnetization will rapidly diminish, and at a certain negative value of the magnetizing force, the magnetization of the iron will presently reach a zero value; but, if the current be broken the magnetization will "spring back" along the line *A B* (*Fig. 1*).

In order to destroy the magnetization of the iron we must pursue our way along the curve to a point at *C*, such that when the current is withdrawn and the magnetization

falls, it will fall along the line *C O*, from *C* to *O*. The iron here, however, will have magnetic properties quite different from those which it had before magnetization.

(*f*) Having reached a large negative value we obtain, on gradually diminishing the force and allowing it to increase in the opposite direction, a curve corresponding to (*e*) and (*d*), and nearly symmetrical on the other side of the axes of *I* and *H*.

The curve *a, b, c, d, e, f* is a graphical summary of the now well-known facts of hysteresis.

(II) *Nearly all reversals of sign in the change of the magnetizing force are accompanied by small changes in the magnetization. In the magnetization curve any reversal starts out along a nearly horizontal line.* (*See Fig. 2.*)

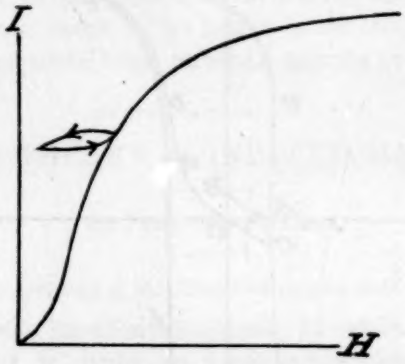

FIG. 2.—Illustrating the effect of a small superimposed cycle in the magnetizing force.

(III) *The fact that a piece of iron submitted to vibrations or mechanical shocks is magnetized and demagnetized more readily and with a smaller hysteresial area than if it remains undisturbed.* The *I H* curve then takes a form of which *Fig. 3* is a type.

(IV) *The phenomena of "time lag" in magnetization.* Ewing finds his magnetometer needle creeping up long after the time when Foucault currents or self-induction could have any effect.

Rayleigh (*Phil. Mag.*, March, 1887) finds that with a second coil he can balance the effect of a magnetizing coil and iron core, at the end of any given time, say five seconds.

If balance is obtained at the moment of making the magnetizing current, then at the end of five seconds there will be a deflection of the magnetometer in *one* direction. But if the balancing coil is so arranged as to give balance at the end of 5 seconds, then there will be an *initial* deflection in the *other* direction.

(V) *Phenomena of stress and magnetism.* These are usually grouped under two heads, viz:

(*a*) Those which occur when a body has first been placed in magnetic field and the stress then made to vary.

(*b*) Those which occur when a body is first placed under a constant stress and the magnetizing force is made to vary.

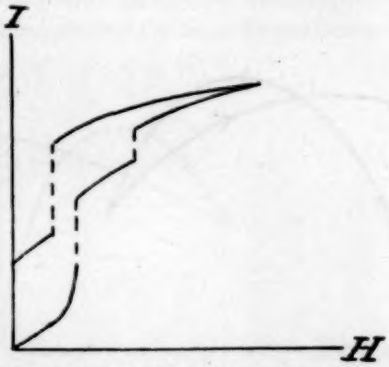

FIG. 3.—Illustrating the effect of tapping on the *I H* curve.

The hysteresis between magnetization and stress may be best illustrated by the curve in *Fig. 4*, derived by Ewing (*Phil. Trans.*, 1885) from experiments on a piece of iron which had been previously strained.

If, however, the wire be a freshly annealed and unstretched one, then the hysteresis is much larger, and we obtain a curve like that in *Fig. 5*, the maximum on the down curve corresponding to a negative load, *i. e.*, to a pressure.

The effect of a *constant* load on the *I H* curve may be seen in *Fig. 6*.

From this it will be seen that longitudinal stress aids magnetization at first, but for larger values of *H* it diminishes it.

(VI) *Effects of heat on magnetization.* In general, perma-

nent magnetism is decreased by heating through any cycle of temperatures. But in the case of induced magnetism we must distinguish between two cases:

(*a*) When the heating is not high the effect is to increase the susceptibility.

(*b*) When the heating is excessive, it decreases the susceptibility.

The foregoing are a few of the hundreds of facts which experiment has recently brought to light. Any tolerably complete explanation of them must include two parts, viz:

(*a*) An explanation of the ampèrian currents (or of molecular magnets on some other hypothesis.)

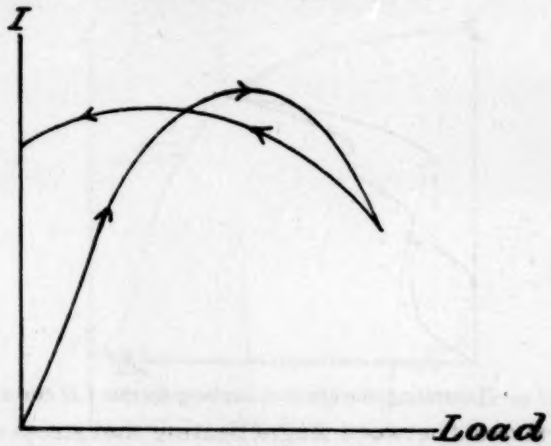

FIG. 4.—Effect of loading an already strained iron wire in a magnetic field.

(*b*) The *arrangement* of Weber's molecular magnets in the mass.

We are here concerned only with the second and apparently less difficult part of the problem.

The first attempt at a theory of magnetic induction is that of Weber, who supposes the molecules of freshly annealed iron to be turned at random in all directions, and to be held in their respective positions by constant forces acting along their respective axes. This hypothesis explains the existence of an upper limit to magnetization; it also explains the experiment of Beetz, in which he obtains a strong magnet by the electrolytic deposition of iron in a

magnetic field; but is condemned by its failure to explain the phenomenon of permanent magnetism.

Maxwell, therefore, modifies Weber's theory by supposing that when the axis of a magnetic molecule is displaced through an angle greater than a certain limiting angle it receives a certain set. Thus amended, the hypothesis of Weber covers a much larger number of facts, *e. g.*, permanent magnetism, and the production of permanent magnetism by moderately high forces only. Maxwell's theory fails, however, to explain such a phenomenon as that of "time lag," which has been so elegantly worked out by Rayleigh and Ewing (*Roy. Soc. Proc.*, June, 1889).

In the *Philosophical Magazine* for September, 1890, Prof. Ewing offers the apparently bold hypothesis of no constraint

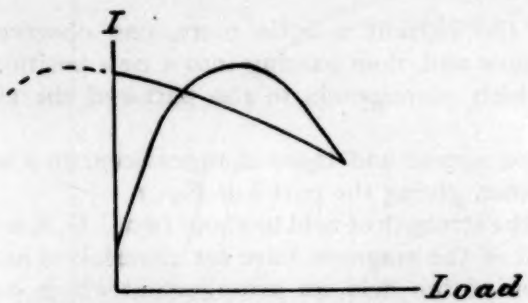

FIG. 5.—Effect of loading a freshly annealed iron wire in a magnetic field.

at all acting on the molecular magnets, save only their magnetic action on one another.

A large model, constructed on the lines suggested in the paper just mentioned, was here exhibited to the Section.

A helix, about three feet long and one foot in diameter, contained within it three tiers of magnets mounted on three glass decks. Each magnet was balanced on a needle-point, the whole arrangement showing in a striking manner the interaction of the magnets and the multitude of different positions of equilibrium which they may assume.

The sufficiency of this hypothesis may best be tested by applying it to explanations of the six typical facts just mentioned.

(I) Stirring the magnets up, with no current in the helix,

we observe that they arrange themselves very much at random, yet more of them pointing north than in any other direction. (The north poles were fitted with damping vanes.) This, of course, represents the magnetization of iron by the earth's field.

Balancing the earth's field by a slight current through the helix, and again stirring up the magnets, we have a piece of freshly annealed iron, with practically no external moment to start with.

A slight increment of current deviates the magnets to some extent, thus giving an external moment, but no new position of equilibrium is assumed, so that on bringing the current back to its initial value, we find the iron without any residual magnetism, which corresponds exactly to the fact of nature.

Increasing the current a little more, one observes a stray magnet now and then passing into a new position of equilibrium which corresponds to the part *a* of the curve in *Fig. 1.*

A little more current and these changes occur in a more wholesale manner, giving the part *b* of *Fig. 1.*

Increasing the strength of field to about two C. G. S. units, we find that all of the magnets have set themselves nearly in the direction of the field, an arrangement which corresponds to the asymptotic part of the *I H* curve.

Diminishing the magnetizing force by gradual steps to zero there remains considerable external moments, which, however, is destroyed and generally reversed by a comparatively small negative force.

In fact, the cyclic curve thus obtained bears a striking resemblance to those actually obtained from a piece of iron. In the *Electrical World*, May 16, 1891, Mr. Arthur Hoopes has three curves, taken from this model under different conditions.

(II) If for any given value of magnetizing field we reverse the sign of change in the current, the magnets will be observed to change direction very slightly, falling back into their nearest position of equilibrium, where they are held by each other until subjected to a change of more con-

siderable size. This, of course, is the second phenomenon mentioned above.

(III) One has only to shake the model, even slightly, to see the effect of tapping a piece of soft iron during magnetization or demagnetization. If the magnets be not very close together, it takes careful handling not to throw them into a new position of equilibrium.

(IV) Allow the magnets to come to perfect rest and then turn one of them with the hand through an angle of 40° or 50°. The disturbance will be propagated along the line at a comparatively slow rate. In this way, Ewing explains "time lag."

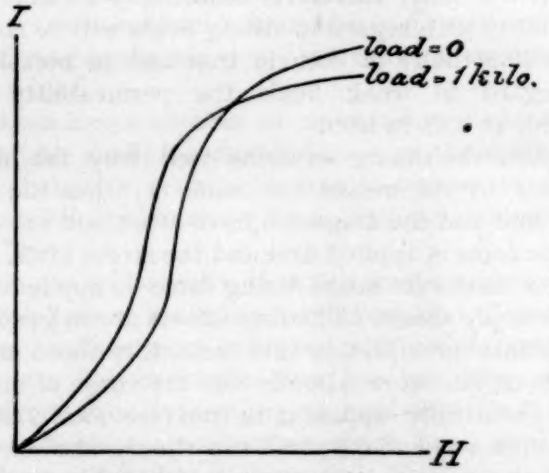

FIG. 6.—Illustrating the effect of a constant load on the *I H* curve.

The great while occupied by the magnets in coming to rest after they have once been disturbed by a change of current, continually increasing or continually decreasing, their external moment, chimes in beautifully with the work of Rayleigh mentioned in "IV" above.

(V) The effect of stress on magnetization is stated as follows in terms of the model by the author of the theory (*Phil. Mag.*, September, 1890): "When pulling stress is applied, those rows of molecular magnets which lie more or less along the direction of the stress have their stability

reduced by the lengthening of the lines of centres; similarly, rows which lie more or less normal to the stress have their stability increased. The resulting effect on the general susceptibility of the material will depend on which of these conflicting influences preponderates. Let pull be applied before magnetization begins, while the metal is still in a neutral state. The stretching of longitudinal lines and the contraction of transverse lines will not only alter the stability of those molecules which continue to lie in their original rows, but will tend to make the members of those rows which are much lengthened swing round and form transverse lines in which they will be more stable than before. We may, therefore, reasonably expect that the permeability with regard to strong fields will be reduced by pull, as it actually is both in iron and in nickel, though with regard to weak fields the permeability may be increased, as it is in iron.

"Again, the theory explains well why the effects of stress are by no means the same (1) when the stress is applied first and the magnetic force after, and (2) when the magnetic force is applied first and the stress after.

"Let a moderate magnetizing force be applied and then begin to apply stress. The first effects are in general large for the strain precipitates into instability those molecular magnets which were already on the verge of instability. This is beautifully apparent in iron (see *Phil. Trans.*, 1885, part ii, plates 63 and 64); and the theory shows why the first effects are not reversible, why they do not disappear when the stress is removed, and why it is only in subsequent applications and removals of the stress that the magnetic changes become cyclic."

(VI) The molecular motions accompanying heat will evidently free the magnetic molecules to some extent from each other and thus allow them more easily to place themselves along the axis of the magnetizing helix. The effect of heat will therefore be in the well-known direction of increasing the magnetization.

The effect of high heat in destroying magnetization is not, however, so readily understood. Ewing suggests that

it may produce rotation of the molecules and thus give the effect of zero external moment.

This much at least may be said, that nearly the whole group of magnets may be placed in rapid rotation by quickly reversing a strong current through the helix. Indeed, most any violent disturbance, such as a shock, will set a large number in rotation, which state they seem to maintain for a long while.

Some facts in the dynamical theory of heat lead one to think that this supposition of rotating molecules may not be so wild as at first it might appear.

The foregoing are some of the facts which fall into line, on the supposition of no constraint among the molecules except their own magnetic attraction and repulsion.

Prof. Ewing has given many more, and everyone should read his paper.

But there are a number of outstanding facts which do not submit so easily to explanation, *e. g.*, the difference of magnetic behavior with reference to temperature in the cases of nickel and cobalt. [*Ency., Brit.*, art. "Magnetism," p. 257.]

It must not be forgotten that this model represents only one single phase of molecular arrangement. Chemical and spectroscopic phenomena indicate a vastly more complicated structure for the molecule than has yet been dreamed of. However, it is interesting to note that Prof. Ewing's hypothesis leads to conclusions which have already been derived from other lines of work.

For instance, the distinction between hard and soft iron in terms of the model is that in the former case the molecules are grouped more intimately than in the latter; while Barus and Strouhal (*Bulletin of U. S. Geol. Survey*, No 14, p. 96), from a study of the viscous and electrical properties of hard and soft iron, have been led to think that hardness is due to heterogeneity of interior arrangement; hard temper being a condition in which the molecules are locked up into a new position of equilibrium, corresponding to a greater storage of potential energy than in the soft condition.

MEMOIR OF JOHN J. WEAVER.

The subject of this sketch was born in Philadelphia, on December 23, 1840, and received his education in the public schools of his native city, having been graduated from the Central High School in the class of 1860.

After several years of experience in commercial pursuits he became associated with Mr. J. S. Pennock, with whom he engaged in the plumbing business, under the firm name of Weaver & Pennock, a connection that was severed by his death on July 14, 1891, in his fifty-first year.

From the outset of his career, Mr. Weaver took a lively interest in every movement designed to extend educational advantages to young men, and he was conspicuously active and zealous in promoting the establishment of trades-schools and in planning and organizing the work of such schools in connection with several institutions and associations, with which he was prominently identified as a member and at times as an officer. To this good work, which with him was a labor of love, he devoted a large share of his time and services.

He was active in establishing the mechanical handiwork schools of the Spring Garden Institute in 1879 (said to have been the first manual training school, properly so-called, founded in the United States), and, to the success of this enterprise, which was due in great measure to his active interest therein as chairman of the committee, and to the large share of public attention it attracted, the subsequent formation of similar schools in connection with the public schools of the city and with Girard College may, we believe, not improperly, be ascribed.

Mr. Weaver was also instrumental in establishing the Trade-school for Plumbers, which was later merged in the trades-schools of the Master Builders' Exchange, of Philadelphia, in which institution he was prominent as an organizer and director.

Mr. Weaver became a member of the Franklin Institute in the year 1871, and from the first, exhibited a warm interest in its work. He was elected to the Board of Managers in 1880 and served acceptably in this capacity to the time of his death. One notable evidence of his activity, which, we believe, is destined to bear good fruit, is the fact that he introduced in the year 1887, a series of resolutions looking to the re-organization of the Institute, and the acquisition of another and larger building, with facilities for greatly increasing its capabilities for usefulness.

The outcome of this was the formation of a committee, of which he was an active member, that has devised some excellent plans, which, it is hoped will be realized at no distant day.

These are but a few of the many enterprises in which Mr. Weaver was actively interested, and which appear to be proper to notice in a memoir intended for the *Journal.*

It seems proper to refer also to his high appreciation of the duties of citizenship, and his warm interest in every movement designed to better the government of his native city.

The most notable traits of Mr. Weaver's character were the activity which he displayed in behalf of any cause in which his sympathies were enlisted; the zeal with which he advocated his views; and the courage with which he championed them in the face of opposition. His enthusiasm, however, was tempered with sound judgment, and was reinforced by a sturdy honesty of purpose, that never failed to command for him an attentive and respectful hearing, while his imperturbable good temper under defeat gained for him the hearty good-will of all who were his opponents in debate.

Mr. Weaver was a man of unusally robust physique, and his lamented death in the prime of his life and usefulness was a most unexpected event.

EDWIN J. HOUSTON,
STACY REEVES,
WM. H. WAHL.

PENNSYLVANIA STATE WEATHER SERVICE.

Announcement by the Committee on Meteorology.

The bill making an appropriation for continuing the State Weather Service having failed to become a law by reason of the objection of the Governor, the regular publication of the Monthly Bulletins in this *Journal* is interrupted.

As heretofore, the Monthly Bulletins will be carefully prepared for publication, at the central office and copies will be furnished to the Weather Bureau at Washington, to the Department of Internal Affairs at Harrisburg, as well as to each observer throughout the State.

It is confidently expected that the Hon. Secretary of Internal Affairs will print these Monthly Bulletins in his annual reports as heretofore, and it is hoped that they will also appear in the *Journal* as early as possible.

At any rate, it is designed to preserve the continuous series of observations.

The Committee, therefore, confidently appeals to the voluntary observers throughout the State to continue their patriotic and gratuitous services, with the assurance that they shall not be thrown away. W. P. TATHAM,

Chairman Committee on Meteorology of the Franklin Institute.

THE following letter received from the Chief of the Weather Bureau is self-explanatory:

WEATHER CROP BULLETIN
and
STATE WEATHER SERVICE DIVISION.

DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
WASHINGTON CITY, July 21, 1891.

Mr. W. P. Tatham, Chairman Meteorological Committee Franklin Institute, Philadelphia, Penna.:

SIR.—I have the honor to inform you that the appointment of Mr. T. F. Townsend, Assistant Director of the Pennsylvania State Weather Service, to the position of Inspector in this Bureau, has made it necessary to relieve him from State Weather Service duties. Mr. L. M. Dey, observer in charge of the Philadelphia station, has been selected to succeed Mr. Townsend, and it is believed that his long experience in the general station work of this Bureau well qualifies him for that assignment.

He will at once consult with you relative to the work of the State Service, and plans for extending the same in the interests of agriculture in the State, and in this connection I would earnestly solicit a continuance of the co-operation of the Franklin Institute in that work, assuring you that I will do all in my power towards increasing the usefulness of that service.

I am, very respectfully,
MARK W. HARRINGTON,
Chief of the Weather Bureau.